BASE

# BOTTOM-UP CLIMATE ADAPTATION STRATEGIES TOWARDS A SUSTAINABLE EUROPE

**Title:** **Economic evaluation of adaptation options**

**Summary:** This report aims to provide guidance and examples for the economic evaluation of adaptation options. It introduces a stepwise approach which is applied in twenty BASE case studies, as well as several tools used within this process. Results from the case studies are described and summarized for each of the steps of the evaluation process and conclusions are drawn regarding a) the results of the evaluation and their transferability and b) the applicability of methods, tools and data sources.

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**Deliverable author(s):** Lead authors:
Volker Meyer, Oliver Gebhardt, Filipe Moreira Alves

Contributing authors: Alessio Capriolo, Ad Jeuken, Jenny Tröltzsch, Zuzana Harmáčková, Eliška Lorencová, David Vačkář, Blanka Loučková, Marie Hubatová, Andreas Hastrup Clemmensen, Anne Haugvaldstad, Anne Jensen, Anne-Mari Rytkönen, Milla Mäenpää, Noora Veijalainen, Tiia Vento, Turo Hjerppe, Inese Huttunen, Markus Huttunen, Mika Marttunen, Antti Parjanne, Anders Branth Pedersen, Helle Ørsted Nielsen, Mette Termansen, Marianne Zandersen, Jakob Stoktoft Oddershede, Margaretha Breil, Jeanne Svalebech, Inês Campos, André Vizinho, Ana Iglesias, Pedro Iglesias, Luis Garrote, Alvaro Sordo, Luis Mediero, Berta Sanchez, Aline Chiabai, Sebastien Foudi, Marc Neumann, Marta Olazabal, Joseph Spadaro, Femke Schasfoort & Mark Zandvoort, Olivia Rendon, Tim Taylor, Sahran Higgins, Roos M. den Uyl, Duncan Russel

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SEVENTH FRAMEWORK PROGRAMME

BASE report

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# 1 Introduction

## 1.1 Background and objective

It is widely acknowledged that despite the manifold efforts to reduce greenhouse gas emissions in order to slow down anthropogenic climate change some of its consequences cannot be averted anymore. Therefore, the need for adapting to these changes has increasingly been recognised as a major societal challenge. Decision-makers, who are increasingly confronted with these challenges and have to make complex decisions over short timespans in a fast-changing world. They are challenged to address the social, environmental and economic resilience of their communities while dealing with tight public budget constraints, competing policy claims and high levels of uncertainty. Confronting this socio-political demand asks for the use of solid economic tools, which have to be themselves efficient, easy to understand and apply, while at the same time scientifically sound and socially accepted.

**Literature review**

There are already a number of process-oriented guidelines and tools for climate change adaptation – on different spatial scales, for different regions, countries and user-groups. All these guidelines provide a sequence of steps leading the reader through the adaptation process, including the economic evaluation of adaptation options.

The PROVIA "Guidance on Assessing Vulnerability, Impacts and Adaptation to Climate Change" (PROVIA 2013) by UNEP provides a comprehensive and state-of-the-art guidance at UN level. The Adaptation Policy Framework (2003) and the corresponding User's Guidebook by UNDP are mainly focused on facilitating climate change adaptation in developing countries.

In the EU context, the "Guidelines on developing adaptation strategies" (EC 2013b) and the web-based European Climate Adaptation Platform "Climate-Adapt" (EC & EEA 2014) are important point of reference. For project managers, the guideline "Making vulnerable investments climate resilient" (EC 2013a) is of particular relevance.

There are also a number of relevant guidelines developed in different member states, e.g. in the UK the comprehensive set of guidelines and tools from UKCIP (Willows &Connell 2003 and the web-tool "Adaptation Wizard", UKCIP 2013), which has set the standard for such guidelines more than ten years ago. Other national examples are Germany's Klimalotse (UBA 2014), the Adaptation Guide for Businesses in Scotland (SCCIP 2010) or the Danish Adaptation platform. A kind of meta-guidance for adaptation is provided by the web-based MEDIATION Adaptation Pathfinder (MEDIATION project 2014).

For decision makers at the regional and local level there are also various guidelines, e.g. Ribeiro et al. (2009) for regional climate change adaptations strategies and e.g. Giordano et al. 2013, Klima-Bündnis 2014 and Gebhardt et al. 2013 for municipality level guidelines.

Although the steps of these different guidelines differ in detail, a "common ground" of five basic steps can be identified:

Problem identification (impact-, vulnerability- or risk assessment)

Selection of potential adaptation options

Evaluation of options

Implementation

Monitoring and ex-post evaluation

In this report we focus in particular on the third step, the economic evaluation of adaptation options. This includes to some degree also the preceding steps (problem identification and selection of potential adaptation options) as they provide important information for the evaluation. However, the following steps 4 (implementation) and 5 (monitoring and ex-post-evaluation) are not addressed in this report (see e.g. upcoming D 5.4 report for implementation analysis).

There are some guidelines and reports which focus particularly on the economic evaluation of adaptation options, e.g. an UN report on assessment of costs and benefits of adaptation options (UNFCCC 2011), UKCIP's reports on costing the impacts of climate change in the UK (Metronomica 2004a, Metronomica 2004b), a study on cost and benefits of selected adaptation measures of the German national adaptation strategy (Tröltzsch et al. 2012), and a guideline for economic evaluation of adaptation options for German municipalities (Gebhardt et al. 2013). Also a section of the PROVIA guidance (PROVIA 2013) and parts of the MEDIATION Adaptation Platform (Mediation project 2014) and a related review article from Watkiss et al. (2014) focus in particular on economic evaluation.

Firstly, the guidelines aim to facilitate the application of different assessment methods such as cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), multi-criteria analysis (MCA), real option analysis (ROA), and robust decision-making (RDM) (Mediation project 2014, Metronomica 2004 a, b, UNEP 2013, Gebhardt et al. 2013).

Secondly, the guidelines explain approaches to collect the input data needed for the economic evaluation, as e.g. relevant methods for cost assessments of natural hazards (Meyer et al. 2013) or methods for the monetisation of environmental impacts such as contingent valuation methods (CVM), choice modelling (CM), travel cost approach, hedonic pricing etc. (Metronomica 2004 a, b, UNEP 2013).

**Aim and approach**

The **main aims** of this report are 1) to provide practical guidance on economic evaluation of adaptation options and 2) to present empirical examples for assessing the cost and benefits of different types of adaptation options. Hence, on the one hand it contributes to the BASE objective 1 and 4 by compiling and analysing data on the social, environmental and economic costs and benefits of adaptation in order to assess adaptation strategies. On the other hand, this report contributes to the BASE objective 2 by developing new, and providing guidance on, methods and tools to assess climate change impacts and to evaluate adaptation options.

Due to the special relevance of the local and regional level when it comes to the implementation of climate change adaptation measures most of the examples will address these levels. The assessments have been conducted and will be presented following a stepwise approach developed by Gebhardt et al. (2013), which has been adjusted for the BASE project (see D.4.1 report and Annex 1 & 2). The approach will briefly be described in section 1.2.

This stepwise approach was applied in 27 BASE case studies in different European regions, for different hazards and different kinds of adaptation options (see section 1.3 for an overview). Each assessment is described in detail in Annex 3. An overview of all the case studies' results for each step of is provided in section 2.

In section 3 conclusions are drawn and recommendations made with regard to a) the *results* of the economic evaluation in the case studies, i.e. about noticeable trends in the results, and b) on the *process* of economic evaluation, i.e. the applicability of methods, tools and data sources. Tools, which are applied in one or more of the case studies, are described in section 1.4.

## 1.2 Introduction of the stepwise evaluation approach

The basic approach for the economic evaluation of adaptation options applied in the BASE case studies is illustrated in Figure 1-1. It consists of five basic steps (see Gebhardt et al. 2013):

1. Preliminary risk assessment
2. Identification of adaptation options
3. Selection of the evaluation method and the evaluation criteria
4. Data collection
5. Evaluation and prioritization

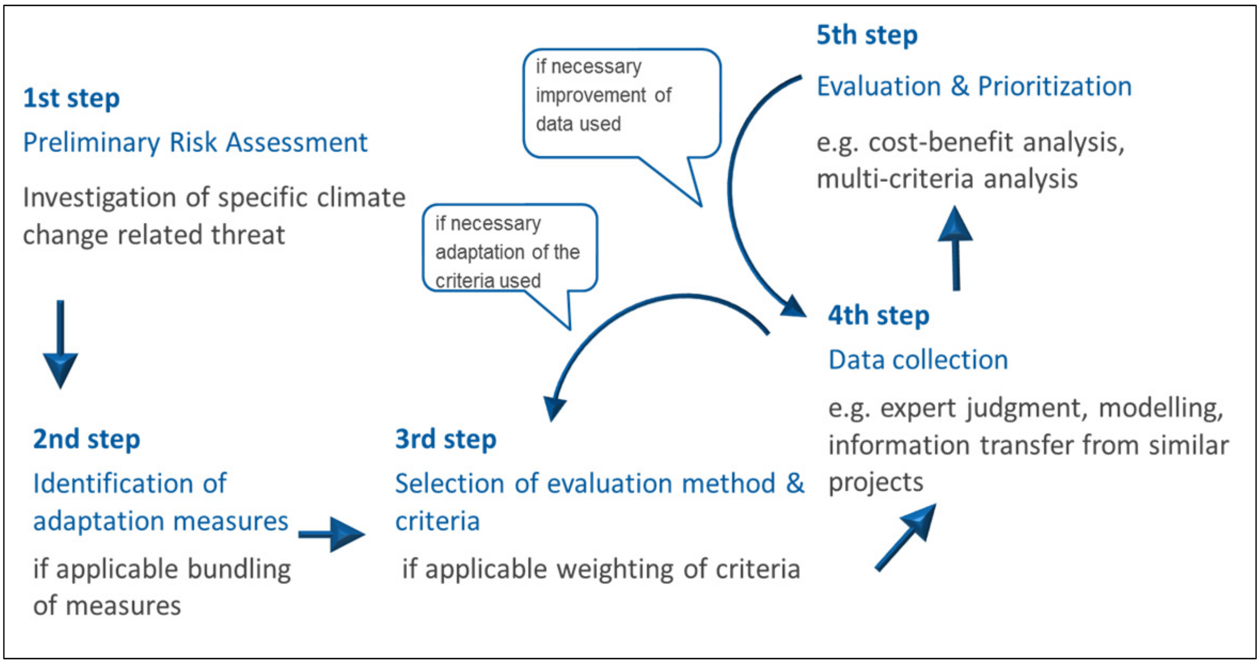



**Figure 1-1: Steps of the process of economic evaluation of adaptation options**

In the following each step will be briefly explained. The detailed guidance with examples can be found in Annex 2. It consists of a list of key and auxiliary questions for each step, which should lead the user through the evaluation process (see also Table 1-1).

### 1.2.1 Step 1: Preliminary risk assessment

In the first step the climate change related problem(s) or risk(s) should be described: Which problems or risks already exist in the current situation and how might these risks change under different climate and socio-economic change scenarios? Which protection measures are already in place?

For the application of the Dynamic Adaptation Pathway (DAP) approach (Haasnoot et al. 2013) it would be necessary to check if adaptation tipping points can be identified, i.e. when current measures and strategies are no longer be able to guarantee defined protection targets.

### 1.2.2 Step 2: Identification of adaptation options

In the second step potential adaptation options need to be identified. First of all, the objectives of adaptation need to be identified. Usually the main objective is mitigation of the climate related risk, but often there are also other secondary objectives of adaptation. Based on these considerations potential options promoting these objectives can be identified.

Furthermore, a baseline option needs to be defined, i.e. the option which all other adaptation options are compared to in the evaluation process. Usually the “business-as-usual” is defined as the baseline option, e.g. keeping the current level of protection, but also other reference states can be applied, e.g. are a “do nothing” option. It is very important to clearly describe the baseline in detail, because costs and benefits of the adaptation options are always related to this baseline.

In addition, it needs to be decided whether single measures should be bundled for the assessment. This is of particular relevance if measures are complementary.

For the application of the DAP approach so called “sell-by”-dates of the different measures or bundles of measures should be identified, i.e. points in time when it is likely that they are no longer able to fulfil the defined targets.

### 1.2.3 Step 3: selection of the evaluation method and the evaluation criteria

The third step consists of two respectively three sub-steps: a) the selection of evaluation criteria, b) the selection of the evaluation method and c) (at least for some evaluation methods) the weighting of the evaluation criteria.

For the selection of **evaluation criteria** the relevant positive and negative properties of the options (costs and benefits) to be considered in the evaluation process have to be determined. This should include economic, ecological and social aspects. Furthermore an appropriate indicator and measurement scale has to be defined. Is the performance of the adaptation options measured in monetary terms or in other quantitative or qualitative terms? This is of course also highly depended on the data availability (see step 4).

Based on the selection of the evaluation criteria and the related objective(s) of adaptation an appropriate **evaluation method** has to be chosen.

The traditional framework for an economic assessment of different alternative options is **Cost-Benefit Analysis** (CBA)[1] (see e.g. Hanley and Spash 1993, Pearce and Turner 1990). The main objective is to find the most efficient, i.e. optimal alternative to be implemented. All benefits of the alternative adaptation options are related to their costs to identify the one with the highest net benefit, compared to a baseline option. However, the CBA requires that all relevant costs and benefits are expressed in monetary terms.

**Cost-Effectiveness Analysis** (CEA)[2] is an economic evaluation approach that relates monetary costs of two or more alternatives to their outcomes (effects) with regard to a predefined non-monetary target indicator. CEA is often used in the field of health services, where it may be inappropriate to monetise health effects (as an intangible, non-market good). Typically, results of CEA are expressed in terms of a ratio where the denominator is the change, e.g. improvement, of a certain indicator (years of life, premature births averted and years gained), while the numerator is the cost associated with the alternative causing this change. The applications of the CEA are restricted to comparisons between options that produce directly comparable outputs measured in the same unit (Birch and Gafni 1992).

**Multi-Criteria Analysis** (MCA)[3] is an alternative or complementary evaluation approach that involves judging the expected performance of each alternative option against a number of objectives or evaluation criteria (Belton and Stewart 2002). In contrast to the CBA, the evaluation criteria used do not have to be measured in monetary terms. In the context of decision support for natural hazard risk mitigation and climate change adaptation, this implies that health and environmental effects of risk mitigation measures can be included in non-monetary terms so that

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

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

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

problems of monetary valuation can be avoided. Instead, however, one faces the problem of weighting the various criteria.

Many different MCA techniques and, hence, decision rules exist, such as e.g. Multi Attribute Utility Theory (MAUT) and Outranking approaches (see e.g. Keeney and Raiffa 1993, Drechsler 1999, Klauer et al. 2006). What most of these approaches have in common is that decision makers and/or relevant stakeholders have to elicit criteria weights (see e.g. Munda 2006, Proctor and Drechsler 2006), i.e. express their preferences regarding these criteria, before aggregating the scores and computing the rankings of alternatives. Weighting approaches such as the "swing-weight" approach and the "point allocation" approach are described in the guidance document (Annex 2). The explicit consideration of decision-maker and/or stakeholder preferences in the assessment process makes MCA a more deliberative and participatory evaluation approach than CBA and CEA. However, for the same reason it is often criticised for being subjective, especially since the preference elicitation methods have been tested and improved to a smaller extent than it has been the case in monetary valuation with stated preference techniques.

Another evaluation approach applied in some BASE case studies is a recent developed (and unpublished) methodology entitled **Participatory Benefit-Cost Analysis** (PBCA). The PBCA is an economic appraisal tool, which has been developed and tested within BASE by the FFCUL partner (CCIAM research group) in order to assess through participatory methodologies the costs and benefits of different adaptation options. It was firstly tested in Cascais (Portugal) case study. The PBCA aims to combine the advantages and strengths of multi-criteria analysis with the rationality of Cost-benefit Analysis (CBA), thereby, evolving from the simplicity of the Simplified Participatory Cost-Benefit Analysis (SPCBA) as proposed by the Climate Resilience Framework – Training Kit (3rd series) – to deliver an all-in-one procedure for action-researchers working in climate adaptation. The PBCA is conceptually and in practice distinct from the SPCBA proposed by the Climate Resilience Framework, namely through the introduction of time differentiation and discounting as well as by introducing complexity into the methodology enabling for different weighting of the criteria, different scales for measuring impact and more impacts to be named and valued by the participants.

PBCA can be defined as a hybrid methodology of economic project appraisal as it is composed of heterogeneous sources and diverse elements, combining interpersonal deliberation and quantitative methodologies to produce both depth and breadth in valuation and appraisal processes. Hybrid methodologies are another growing trend within economic project appraisal tools and methods as they "*resituate specialist knowledge claims through attention to their framing conditions and boundaries of uncertainty, while co-producing new forms of citizen and stakeholder expertise, thus opening up the appraisal of projects, plans, programs, and technologies to other forms of framing and reasoning*" (Davies, 2006: 235).

Two other decision-making approaches considering in particular the uncertainties in climate change adaptation are **Real Option Analysis** (ROA) (e.g. Woodward et al. 2014) and **Robust Decision Making** (RDM) (Lempert et al. 2003).

### 1.2.4 Step 4: Data collection

In the fourth step the necessary data for the evaluation criteria needs to be collected. The sources of the data are of course very case specific, e.g. costs for the construction of a dike or a green roof. Data on the damage reducing effect of certain adaptation options can for instance be based on flood damage estimation models. If no models or other sources are available, estimations for the effects of different adaptation options can be also obtained by consulting experts.

Such input data is often to varying degrees uncertain (uncertainties in models, data sources, expert judgements). In order to make such uncertainties transparent in the overall evaluation they need to be documented in the data, e.g. in terms of ranges or probability distributions.

For running the evaluation also the time frame of the evaluation (usually the lifetime of the project) and the discount rate (the relative weight given to future costs and benefits) need to be determined.

### 1.2.5 Step 5: Evaluation and prioritization

Finally, in the fifth step, the evaluation of the different adaptation options is carried out, based on the evaluation method and criteria chosen. The specific outcome of the evaluation depends on the evaluation methods (e.g. net present values or benefit-cost ratios for CBA, cost-effectiveness ratios for CEA or different types of scores for different MCA approaches). Based on these a ranking and prioritisation of adaptation options can be derived (under consideration of the uncertainties involved).

As illustrated in Figure 1-1 this stepwise evaluation process includes some potential feedback loops, e.g. if it turns out that the necessary data for selected evaluation approach is not available or cannot be collected with reasonable effort it might be advisable to revise the evaluation method applied (feedback loop from step 4 to step 3). If it is not possible the collect monetary estimates for a crucial criterion it might be advisable to complement a partial CBA with a MCA.

Another feedback loop relates to the data collection: If there is a high degree of uncertainty in the input data to calculate a final ranking which is statistically significant and/or acceptable for the decision makers, it is advisable to make, if possible, an additional effort to improve the quality of input data.

In general, the choice of an appropriate evaluation approach is always a trade-off between accuracy and effort. It depends very much on the objective of the decision process (pre-feasibility study vs. final investment decision) the scale of the analysis and the availability of pre-existing data. The stepwise evaluation process can be therefore also applied in an iterative way, e.g. a MCA for a pre-feasibility study to identify the two or three best options and a more detailed CBA for the final investment decision, or, an approximate partial CBA to test if an option is likely to be efficient in general, and then a more detailed participatory MCA to evaluate different variants of this options (see Copenhagen case study in the Annex 3).

**Table 1-1 Questions for economic evaluation of adaptation options in the case studies**

| Key questions | Auxiliary questions |
|---|---|
| **Step 1 Preliminary risk assessment (and identification of adaptation tipping points)** | |
| What is the climate change related problem/risk you would like to reduce by adaptation? | Which problems already exist, what is/are the current risk/s? |
| | Which assets and sectors are at risk under current climate variability? |
| | Which adaptation or protection measures are already in place? |
| | How do these risks presumably change due to climate and socio-economic change?<br>What are the main drivers, impacts and affected sectors? |
| | Which climate and socio-economic scenarios are used? |
| Which adaptation tipping points can be identified? | Can adaptation tipping points, critical levels for adaptation, be defined for this current strategy? (= when objectives are not met anymore due to changes) |
| | When (roughly) will these critical levels be reached due to climate change or socio-economic change<br>Give appropriate period (2015-2030, 2030-2050, after 2050) for each considered combination of climate and socio-economic scenario. |
| **Step 2 Identification of adaptation options and adaptation pathways** | |
| What are the alternative adaptation | What are the primary and secondary objectives of adaptation? |

| Key questions | Auxiliary questions |
|---|---|
| options? | |
| | What are potential options to meet these objectives? |
| | What is your baseline option ("Business-as-usual"-option)?<br>• What is the ambition level of this baseline strategy? Maintaining current risk levels or current protection levels (implying with CC risks may increase)?<br>• Is a current backlog of investments for adaptation measures included or excluded?<br>• Does it include only planned adaptation or also autonomous, non-planned adaptation? |
| | Are there complementary measures? Is it appropriate to bundle these measures? |
| What are alternative adaptation pathways? | What is the "sell-by"-date of the measures or bundles of measures? I.e. when will they – under conditions of climate change – not any longer be able to meet the defined objectives? |
| | What would be alternative measures or bundles of measures at these "tipping points"? |
| **Step 3a Selection of evaluation criteria** | |
| Which evaluation criteria should be used? | What are the relevant positive and negative properties of the measures (costs and benefits) to be considered in the evaluation process (economic, ecological and social effects)? |
| | What is the appropriate unit to measure each of these criteria? Is the performance of the adaptation options measured in qualitative, monetary or other quantitative terms? |
| **Step 3b Selection of evaluation method(s)** | |
| What is the appropriate evaluation method? | Is it possible to express all relevant cost and benefit criteria in monetary terms?<br>(→ Cost-benefit analysis) |
| | Is it possible to express the positive effect (objective) by a single non-monetary indicator?<br>(→ Cost-effectiveness analysis) |
| | Are there several relevant criteria, which cannot or cannot easily be expressed in monetary terms?<br>(→ Multi-criteria analysis) |
| **Step 3c Weighting of evaluation criteria** | (Applicable only to Multi-criteria analysis) |
| What are the preferences of stakeholders regarding the different evaluation criteria? | Are there different stakeholder groups with varying preferences regarding the evaluation criteria? |
| | Which weight do stakeholders and/or decision makers attach to a substantial change in the performance of the adaptation options regarding each evaluation criterion?<br>(→ Swing-Weight method) |

| Key questions | Auxiliary questions |
|---|---|
| **Step 4 Data collection** | |
| What are the costs of the alternative adaptation options?<br>What are the benefits of the alternative adaptation options? | For each cost and benefit criteria selected in step 3a:<br>What potential data sources are available, including damage & impact assessment methods or existing CBA studies on adaptation measures? |
| | If no relevant data sources are available and modelling cannot be undertaken: Which experts can estimate proxies for assessing the performance of measures regarding the respective criterion? |
| What is the evaluation time frame? | What is the lifespan of the measure with the longest lifetime? |
| Which discount rate should be applied? | Which discount rate is recommended by national guidelines for climate change adaptation measures (or public investments)?<br>Is it a linear discount rate or any other type (i.e. declining, hyperbolic, etc.)?<br>(In addition, for testing the sensitivity of the results with regard to the discount rate(s) used, also apply a low and high discount rate (1% and 5%)).) |
| How to deal with data uncertainty? | Can uncertainties related to the performance of the measures with regard to certain evaluation criteria be described as a value range (min-max), a triangular distribution (min, most likely, max) or any other kind of probability distribution of values? |
| **Step 5 Evaluation and prioritization** | |
| What is the ranking order of alternative adaptation options (measures, bundles of measures or pathways)? | For Cost-benefit analysis:<br>What is the net-present value (discounted benefits – discounted costs) of the alternative options?<br>What is the Benefit-cost ratio? |
| | For Cost-effectiveness analysis:<br>Which alternative achieves a defined objective at lowest costs?<br>What is the cost-effectiveness ratio? |
| | For Multi-criteria analysis:<br>Which adaptation option performs best?<br>(e.g. for the PROMETHEE approach: Which option has the highest net flow?) |
| | What are the uncertainties associated with the performance of the different options?<br>Is there and, if so, to what extent is there uncertainty in the ranking of options?<br>Is it possible to determine which option most likely performs best or is it necessary to gather further information to reduce uncertainty (go back to step 4)? |

## 1.3 Case study overview

The BASE case studies that conducted an economic evaluation of adaptation options are shown in Table 1-2. A detailed case study description can be found in the BASE report D5.1 (Campos et al. 2014) or in the single case study contributions in Annex 3 of this report.

**Table 1-2: Case study overview**

| Case Study | Partner | Base region | Hazard/Risk |
|---|---|---|---|
| Timmendorfer Strand | EI | Central & East | Floods (coastal) |
| Green roof | CzechGlobe | Central & East | Ecosystem degradation |
| Jena | UFZ | Central & East | Heat stress, 3 sub-cases |
| Prague | CzechGlobe | Central & East | Floods (fluvial) |
| Prague | CzechGlobe | Central & East | Heat stress |
| Copenhagen | DBT | North | Floods (coastal) |
| Copenhagen | DBT | North | Floods (pluvial |
| Kalajoki river basin | SYKE | North | Floods (fluvial) |
| Kalajoki river basin | SYKE | North | Water quality |
| Holstebro | AU | North | Floods (fluvial) |
| Kalundborg | DBT | North | Floods (coastal) |
| Venice | CMCC | South | Floods (coastal) |
| Alentejo | FFCUL | South | Water scarcity /Droughts |
| South Aveiro Coast | FFCUL | South | Floods (coastal) / Coastal erosion |
| Cascais | FFCUL | South | Floods (pluvial) |
| Tagus Water District (Madrid) | UPM, BC3 | South | Heat stress |
| Doñana | UPM | South | Water scarcity / Droughts |
| Rotterdam | Deltares | West | Floods (fluvial, coastal) |
| Cornwall | UniExeter | West | Health effects (caused by elevated UV irradiance and exposure) |
| Leeds | UniLeeds | West | Floods (fluvial), 3 sub-cases |
| South Devon Coast (Railway) | UniExeter | West | Floods (coastal) |
| South Devon Coast (Flood risk management) | UniExeter | West | Floods (fluvial) |
| Mental Health UK | UniExeter | West | Health effects caused by heat stress |

## 1.4 Models and tools used

Several different models or tools used in one or more of the BASE case studies. These tools are either used in step 4 to gather the necessary input data for considered climate change impacts (InVEST, URBAHT, Planning Kit DPRD, VEMALA) or in step 5 for the evaluation of different adaptation options (PRIMATE, KUTOVA, Planning Kit DPRD). The different tools are briefly presented below and further analysed to understand its concrete application and usefulness in different case studies.

### 1.4.1 InVEST

The Integrated Valuation of Ecosystems Services and Trade-off's (InVEST) is a free, open-source software developed under the Natural Capital project (NatCap) in order to better integrate the biophysical, socio-economic and other dimensions and values of nature into decision-making processes. The underlying reasoning states that ecosystems, if properly managed, yield a flow of services, which are vital to humanity, including the production of goods (e.g., food), life support processes (e.g., water purification), and life fulfilling conditions (e.g., beauty, recreation opportunities), and the conservation of options (e.g., genetic diversity for future use). Despite its importance, this natural capital is poorly understood, scarcely monitored, and—in many cases—undergoing rapid degradation and depletion. To better align ecosystem conservation with economic forces, the NatCap developed InVEST, which quantifies and maps the values of ecosystem services. The modelling suite is best suited for analyses of multiple services and multiple objectives. The current models, which require relatively little data input, can identify areas where investment may enhance human well-being and the environment.

In the context of BASE, this software tools and its models were used in two separate case studies – Alentejo (Portugal) and Green Roofs (Czech Republic) – in order to assess carbon storage, sediment retention and water purification services due to land uses changes related with climate change adaptation measures yielding graphical representations of ecosystems services under different scenarios for land use changes.

### 1.4.2 URBAHT

URBAHT is a tool for the assessment of site-specific heat stress levels under changing climate conditions and/or for varying configurations of a spatial unit, e.g. as a consequence of the implementation of an urban planning project. On the basis of these assessments users can compare different situations in which either the climate or the construction related parameters or both of them are change at the same time for the same spatial unit. In a single run any pair of the following 4 states can be compared using URBAHT:

| | **Current climate conditions** | **Future climate conditions** |
|---|---|---|
| **Current spatial configuration** | Current heat stress level | Heat stress level for future climate conditions |
| **Changed spatial configuration** | Heat stress level for changed spatial configuration | Heat stress level for changed spatial configuration and future climate conditions |

**Figure 1-2: Comparative assessments with URBAHT**

The software uses an algorithm to process data on various structural and climate factors, which can easily be obtained from public sources. The following input data is requested:

**Table 1-3: Structural and climate input parameters for URBAHT**

| Structural parameters | Climate parameters |
|---|---|
| Area type | Global radiation |
| Construction type | Average maximum temperature in summer quarter |
| Portion of impervious area (without buildings) | Average precipitation in summer quarter |
| Portion of impervious area covered by buildings | Influence of cold air flows for site-specific micro climate |
| Average height of buildings | Average wind speed |
| Average albedo value of surfaces | |
| Portion of water areas | |
| Portion of green areas trees | |
| Portion of area covered by bushes | |
| Portion of area covered by lawn | |
| Irrigation of at least 50% of green areas in summer quarter | |
| Total population of the city | |
| Population density of study area | |

The UHI potential scores determined with URBAHT range from 0 (no heat stress) to 10 (maximum heat stress level) (Figure 1-3).

| UHI potential score | Heat stress level |
|---|---|
| 0 | None |
| 1 | Very low |
| 2 | Low |
| 3 | Moderate |
| 4 | Medium |
| 5 | Slightly elevated |
| 6 | Moderatly elevated |
| 7 | Strongly elevated |
| 8 | High |
| 9 | Very high |
| 10 | Maximum |

**Figure 1-3: URBAHT UHI potential score scale**

The scale is identical for all climate zones. The scores do not reflect, as for instance predicted mean votes (PMV), specific levels of thermal (dis)comfort. Therefore, it is recommended to rather interpret changes or differences in UHI potential scores than the absolute heat stress level values.

URBAHT is applied in the Jena and Prague cases.

### 1.4.3 Planning Kit DPRD

The Planning Kit DPRD was developed as a decision support tool to evaluate a wide variety of flood risk management strategies in the Netherlands. The planning kit contains a set of strategies that reduce the chance of flooding as well as measures, which reduce the flood consequences.

The tool is implemented in the C# programming language and consists of a database, a calculation module, a user interface and a post-processing module that transforms the results in the desired output (Kind et al. 2014). The tool estimates the nominal and present values of all costs of the measures and the cost of expected flood damages.

The user can choose to calculate the costs of the adaptation measures for different types of flood protection standards, climate change and socioeconomic development. The measures can be implemented at any year in the period 2017-2100. However, some measures imply lead time before implementation. The flood protection standard is expressed as a flood probability per year (Van der Most et al. 2014). The program estimates the dike height necessary to meet the flood protection standards.

For each dike, a database provides hydraulic information concerning the actual height of the dike, the water levels for different return periods, water level rises due to climate change, soil subsidence, and so on. Also information on the cost of improving the dikes, in steps of 10 centimetres up to 2 meters, is included in the database (Kind et al. 2014).

In case the dike height is lower than the design water level, dike reinforcements are considered. However, some dikes are not strong enough to withstand water and have severe 'piping' problems. For the dike sections where the piping problem is known, the Planning Kit addresses the piping problem by strengthening the dikes, for which also costs are included in the database (Kind et al. 2014).

The necessary dike height is determined by using a design horizon of 50 years. This means that after heightening, the dike has to withstand the dike height test for 50 years after the rejection, on basis of projections for climate change and soil subsidence. In case measures are chosen that lower the design water level, such as room for the river measures, the dike height test can be probably withstand longer. This will postpone dike reinforcement. The postponement of dike investments ultimately translates in a lower present value of the total investment cost, which represents an important part of the benefits (Kind et al. 2014).

The Planning Kit also computes the expected flood damages in the area on an annual basis. This includes property damages as well as damages due to business interruption, indirect damages, and the damages due to casualties (Kind 2013, Eijgenraam et al. 2014, Boþkarjova et al. 2012).

The Planning Kit calculates the present values of all costs of measures and of expected damages. For discounting costs and benefits, discount rates between 3 and 7 per cent can be chosen. In BASE the Planning Kit is applied in the Rotterdam case study. Please note that the Planning Kit is not the same tool, which is used for flood risk assessment on European level in BASE WP3 (see BASE deliverable 3.1).

### 1.4.4 Nutrient loading model VEMALA

VEMALA is an operational, national scale, nutrient (phosphorus and nitrogen) loading model for Finnish watersheds. It simulates runoff processes, nutrient processes, leaching and transport on land, in rivers and in lakes (Huttunen et al. 2015). The VEMALA model provides an estimate of external loading, outflow loading, retention of nutrients in all ca. 58,000 lakes in Finland, as well as nutrient loading source apportionment into main sources - agriculture, forests, scattered settlements and point sources. The present version of the model consists of a catchment scale, semi-process-based model of total nitrogen (TN) loading, VEMALA-N, and a field scale process-based model for total phosphorus (TP) loading, VEMALA-ICECREAM (Huttunen et al. 2015).

ICECREAM is based on the CREAMS (Knisel 1980) and GLEAMS (Knisel 1993) models, and developed for Finnish conditions by Rekolainen and Posch (1993). Since then, several studies have been published describing its further development and applications (e.g. Tattari et al. 2001, Yli-Halla et al. 2005, Bärlund et al. 2009, Jaakkola et al. 2012). ICECREAM calculates the hydrology of each field plot based on the so-called bucket model. Surface runoff is calculated with the SCS curve number method (Soil Conservation Service 1972) and macropore flow for clay soils is determined with the method developed by Jaakkola et al. (2012). The phosphorus simulation is based on the flow between three mineral P pools and three organic P pools. Particulate and dissolved phosphorus are lost via surface runoff and macropore flow, and dissolved phosphorus also via the water percolating through the soil profile. Erosion is calculated with the modified USLE model (Foster et al. 1977).

Total nitrogen loading is simulated by the VEMALA-N model (Huttunen et al. 2015b), which is a catchment scale N leaching model with six land uses defined: spring cereals, winter cereals, grassland, root crops, green fallow and forest. In the VEMALA-N model, nitrate ($NO_{3-}$) and organic nitrogen are described separately. Organic nitrogen is modelled using a concentration-discharge relationship, in which subsurface and base flows are characterized by different organic nitrogen concentrations. Nitrate is simulated using a semi-process-based model similar to the INCA approach (Rankinen et al. 2004). $NH_4^+$ storage in the soil is modelled and linked to the soil organic nitrogen and nitrate. The processes included to simulate nitrate leaching are mineralization, nitrification, denitrification, immobilization, plant uptake, fertilizer input, dissolution and nitrogen leaching.

The data used as input include: (1) meteorological data (daily air temperature and precipitation, Finnish Meteorological Institute), (2) hydrological data (daily discharge and water levels, Finnish Environment Institute), (3) water quality monitoring data (Finnish Environment Institute), (4) agricultural field data for all fields in Finland (soil texture, slope, crop from a private soil analysis service company Viljavuuspalvelu Oy), (5) annual point loads from the Compliance Monitoring Data System (VAHTI), (6) number of scattered dwellings from building and dwelling register of Finland. VEMALA is used in the Kalajoki case study.

### 1.4.5 Economic agricultural sector model DREMFIA

Also in the Kalajoki case study the economic agricultural sector model DREMFIA is used. It allows evaluating changes in regional level agriculture throughout Finland under different scenarios. The model simulates production and foreign trade of agricultural commodities, as well as land use (areas under crops and set aside) and production intensity (fertilization, land use) annually from 1995 up to 2020 and produces a steady state static equilibrium for 2030, 2040 and 2050. The model assumes rational economic behaviour and competitive markets, replicates realized production and land use 1995-2012, and produces realistic development paths of agriculture (see Lehtonen 2001 and 2013 for details).

### 1.4.6 KUTOVA

Again, in the Kalajoki case study, the spread sheet tool KUTOVA, developed in the Finnish Environment Institute (SYKE), is used for assessing the cost-effectiveness of agro-environmental measures at catchment scale. The tool can be used to compare single measures by their cost-effectiveness or achievable phosphorus loading reduction rate. With the tool it is also possible to build cost-effective combinations of measures, where the interactions of the measures are taken into account. The tool includes 19 different measures from agriculture, forestry, scattered settlement and peat mining (Hjerppe, Väisänen 2015).

KUTOVA-tool utilizes the loading estimates of WSFS-VEMALA model as input data. Additionally the reductions achieved with selected combinations of measures can be fed back into the WSFS-VEMALA model for the calculation of impacts in receiving waters.

### 1.4.7 WAAPA

The Water Availability and Adaptation Policy Assessment model WAAPA (Garrote et al. 2011) links water supply, demand and management and is used to analyse policy options.

The WAAPA model may be used to compute the water availability and demand-reliability curves, which provide a simple way to evaluate water availability under different policy and climate change scenarios. WAAPA simulates the joint operation of all reservoirs in a basin to satisfy a unique set of demands. Basic inputs to the WAAPA model are the river network topology, the reservoir characteristics (monthly maximum and minimum capacity, storage-area relationship and monthly evaporation rates), the naturalized stream flow series entering different points of the river network, the environmental flow conditions downstream of reservoirs and monthly values of urban and agricultural demands for the entire basin. The model is based on the mass conservation equation, and main assumptions refer to how reservoirs are managed in the system: to supply demands for any given month, water is preferentially taken from the most downstream reservoir available, since spills from upstream reservoirs can be stored in downstream ones.

Model architecture is summarized in Figure 1-4. The WAAPA model is based on a basic reservoir operation model. The reservoir operation model takes as input the monthly inflows, the monthly required environmental flow, the monthly demand values sorted by priority with the corresponding return flow, the reservoir data (monthly maximum and minimum capacity, storage-area relationship and monthly evaporation rates) and the reservoir initial condition (initial storage). The result of the reservoir operation model is a set of time series of monthly volumes supplied to each demand, monthly storage values and monthly values of spills, environmental flows and evaporation losses. From this output, demand reliability can be computed applying any conventional procedure. Additionally, WAAPA can be operated as a joint reservoir operation model that combines all reservoirs in a basin to satisfy a unique set of demands. Reservoirs are ordered by priority (water is taken preferably from reservoirs with higher priority). In each time step, the model performs the following operations:

- Satisfaction of the environmental flow requirement in every reservoir with the available inflow. Environmental flows are passed to downstream reservoirs and added to their inflows.
- Computation of evaporation in every reservoir and reduction of available storage accordingly
- Increment of storage with the remaining inflow, if any. Computation of excess storage (storage above maximum capacity) in every reservoir.
- Satisfaction of demands ordered by priority, if possible. Use of excess storage first, then available storage starting from higher priority reservoirs.

WAAPA is used in the BASE case study Doñana, Spain.

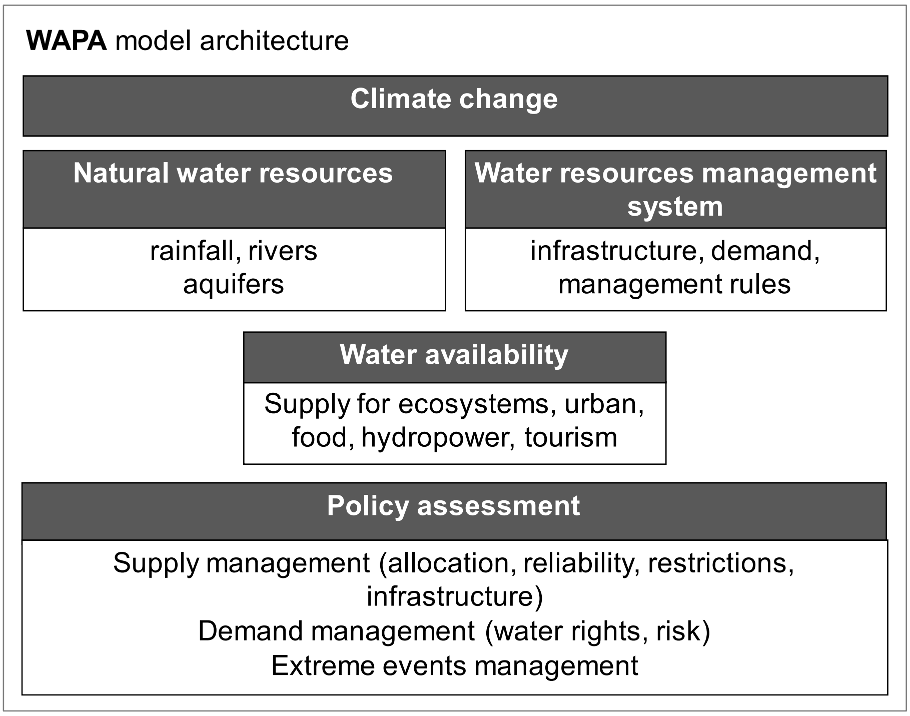



**Figure 1-4: Architecture of the Water Availability and Adaptation Policy Assessment model (WAAPA)**

#### 1.4.8 PRIMATE

The tool PRIMATE (An Interactive Software for Probabilistic Multi-Attribute Evaluation) allows for the comparative assessment of alternative adaptation measures by means of CBA and/or participatory MCA, considering different kinds of uncertainties.

The aim of the CBA is to indicate whether an adaptation option is efficient, i.e. provides a higher net benefit than the baseline alternative (no adaptation-option). When comparing several adaptation measures with the baseline option PRIMATE identifies the most efficient alternative on the basis of the net benefits calculated. The MCA module in PRIMATE is based on the outranking concept PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluations), which performs a pairwise comparison of all alternatives identified across all evaluation criteria selected counting arguments “in favour” and “against” each option.

PRIMATE allows for the simultaneous and explicit consideration of the varying preferences of different decision makers and/or stakeholders involved in the decision making process. Uncertainties in the criterion values can be considered by using a Monte Carlo simulation approach (Stochastic PROMETHEE II), i.e. several PROMETHEE analyses are performed for a random sample of criterion values within a range to be defined. The effects of the varying preferences and the uncertainty ranges of the criterion values are documented in the final results.

The results of the MCA are presented in PRIMATE in various ways. This includes not only the overall performance of an alternative considering all criteria and preferences but also its strengths or weaknesses with regard to specific criteria or decision makers’ preferences. This enhances the transparency of the decision making process and facilitates the identification of compromise solutions.

For a guided tour offering comprehensive information on the methodical foundations of PRIMATE as well as practical advice for its use see Drechsler et al. (2009). Figure 1-5 shows the main steps of PRIMATE.

The use of PRIMATE requires the identification of *adaptation options* to be compared. A set of *evaluation criteria* has to be defined. In BASE this could be on the one hand the costs of a certain adaptation option or pathway, and, on the other hand its benefits, e.g. economic, social and ecological benefit criteria (e.g. annual average flood damage avoided, coming from the flood risk model, annual average drought damage avoided, coming from the water scarcity model, health effects avoided, coming from the health model, effects on ecological flows, coming from the ecological flow model, etc.). The *preference functions* (indifference threshold, threshold of strict preference, shape of the preference function) for each decision maker and every criterion have to be specified (for details see Drechsler et al. 2009, p.3, p.18-19). The *weight* of every criterion has to be determined by each decision maker in accordance with its relative importance. Data on the *performance* of the alternatives with regard to each evaluation criterion has to be collected.

There a few options to include *participatory elements* in the evaluation process when using the CBA module (e.g. selection of cost categories to be included, selection of adaptation options to be compared), but the MCA module offers some participatory elements as stakeholders need to express their preferences with regard to the different evaluation criteria (*preference functions*) and have to assign *weights* to the criteria representing their relative importance in the decision making process.

PRIMATE is applied in several BASE case studies, i.e. Jena, Copenhagen, Cascais and Rotterdam.

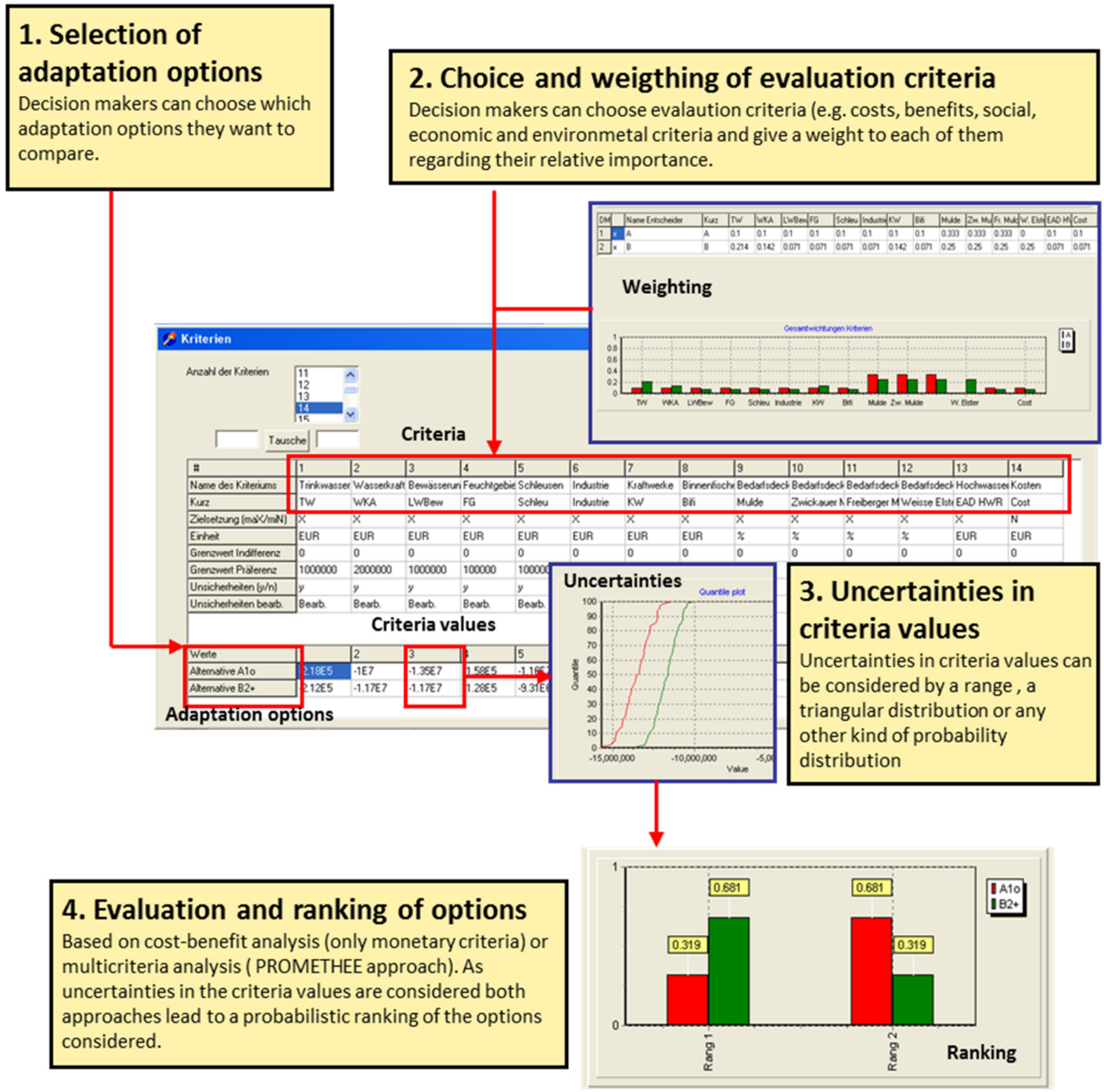



**Figure 1-5: Main steps of the application of PRIMATE**

# 2 Overview of case studies' results for each step

In this section the main results from the different BASE case studies will be summarised for each of the five steps described in section 1.2. A detailed description of each case study can be found in Annex 3.

## 2.1 Step 1: Risks addressed by the case studies

**Risks addressed**

- As Table 2-1 and Table 2-2 show many of the BASE case studies are dealing with flood risks: some of them with coastal flooding (Copenhagen, Timmendorfer Strand, Venice, Kalundborg, Aveiro Coast), some with fluvial flooding (Prague, Holstebro, Kalajoki river basin, Leeds, Cascais). The Rotterdam and South Devon case study deal with both, coastal and fluvial flooding, and the Copenhagen case study with coastal and pluvial flooding.
- Four case studies are addressing heat stress and related risks to health (Jena, Prague, Madrid, Cornwall, UK Health),
- Two case studies address water scarcity risks (Alentejo, Doñana), and there are singular case studies evaluating water quality issues (Kalajoki river basin) and risks of ecosystem degradation (Green roof).

**Existing protection**

- As Table 2-2 shows in some of the case studies some measures mitigating existing risks have been already established (Timmendorfer Strand, Rotterdam, Prague, Copenhagen, Rotterdam, Leeds, South Devon Coast, Alentejo) but in other cases no adaptation measures have been implemented, yet (Jena, Prague heat stress).

**Climate change effects**

- Almost all cases report an expected increase in risks due to climate and socio-economic change. For Prague, however, no clear quantified trends exist for the expected change in flood frequencies. In the Kalajoki river basin it is even likely that probability of flooding will decrease as a consequence of climate change.

**Adaptation pathways**

- Only three case studies applied the Dynamic Adaptation Pathways (DAP) approach and defined adaptation tipping points for changing path (Aveiro, Rotterdam and Prague).
- For the Prague urban heat stress assessment, a certain heat stress level determined by the URBAHT tool is defined as an adaptation tipping point, i.e. a moderate elevated value (6) of UHI potential.
- In the Rotterdam case study, all measures or bundles of measures should guarantee a certain protection level. In this case option costs are used as adaptation tipping points: In each period the cheapest option to achieve this target is chosen and if an alternative becomes cheaper in the next periods this is defined as a adaptation tipping point to move to that option.
- In the Aveiro coast case study, Scenario Workshops were combined with participatory Adaptation Pathways creating the Scenario Workshop Adaptation Pathway - SWAP methodology. Different bundles of measures were combined for each stretch of the coastline and evaluated by the local stakeholders using a set of criteria and two existing adaptation tipping points.

**Table 2-1: Primary risks addressed in BASE case studies**

| Primary risks | Case studies |
|---|---|
| **Floods (coastal, fluvial, pluvial)** | Timmendorfer Strand (Coastal)<br>Venice (Coastal)<br>Kalundborg (Coastal)<br>Aveiro Coast (Coastal)<br>Copenhagen (Coastal, Pluvial)<br>Cascais (Pluvial)<br>South Devon Coast (Coastal, Fluvial),<br>Rotterdam (Coastal, Fluvial)<br>Prague (Fluvial)<br>Holstebro (Fluvial)<br>Kalajoki river basin (Fluvial)<br>Leeds (Fluvial) |
| **Heat stress** | Jena<br>Madrid<br>Prague<br>UK Health<br>Cornwall |
| **Ecosystem degradation** | Green roof |
| **Water quality** | Kalajoki river basin |
| **Water scarcity** | Alentejo<br>Doñana |
| **Health** | UK Health<br>Cornwall |

**Table 2-2: Overview step 1: Risks addressed by BASE case studies**

| Case study | Current risk/s | Current protection | Climate change effects |
|---|---|---|---|
| Timmendorfer Strand | Coastal flooding | Old coastal defences | Two sea-level rises of 0.30 cm (minimum scenario) and 0.50 cm (maximum scenario) are used which are in line with moderate (RCP2.6) and medium (RCP4.5 und RCP 6.0)- IPCC projections. |
| Green Roof | Extreme weather events, extreme temperature, water scarcity and land use changes affecting ecosystems | None | Ecosystems affected by changes in<br>• Precipitation regimes: +67 mm/year (RCP4.5), +37 mm/year (RCP8.5)<br>• Evapotranspiration regimes: -23 mm/year (RCP4.5), +28 mm/year (RCP8.5)<br>More frequent wind storms and bark beetle outbreaks<br>Water shortages (based on the participatory input by local stakeholders – not modelled based on climate change scenarios)<br>Ecosystems, forestry, tourism sector negatively affected |
| Jena - Winzerberge | Current heat stress level is rather low but will increase substantially in the future | Heat stress reduction has not been regarded explicitly when site has been developed in the 1980s | Average maximum temperature in summer will increase by 3 K (CMIP5, RCP 4.5) respectively 7 K (CMIP5, RCP 8.5)<br>Number of hot days will be up to three times (CMIP5, RCP 4.5) respectively four times (CMIP5, RCP 8.5) higher than under current climate conditions<br>Heat stress potential score for status quo spatial configuration doubles (CMIP5 RCP 4.5) respectively triples (CMIP5 RCP 8.5) by the end of the century (2070-2100) |
| Jena - Inselplatz | Medium heat stress potential for status quo spatial configuration under current climate conditions (score 3.7)<br>Heat stress potential will increase substantially in the future | Site is mainly been used as a parking ground<br>17% of the site is covered by trees | For development of average maximum temperature in summer and number of hot days see Jena - Winzerberge<br>Heat stress potential score for status quo spatial configuration increases from 3.7 to 5.6 – slightly/moderately elevated (CMIP5 RCP 4.5) respectively 7.4 – strongly elevated/high (CMIP5 RCP 8.5) by the end of the century (2070-2100) |

| Case study | Current risk/s | Current protection | Climate change effects |
|---|---|---|---|
| Jena - Zwätzen | Heat stress potential will increase substantially in the future | None - site is currently used as grassland | For development of average maximum temperature in summer and number of hot days see Jena - Winzerberge<br>Number of hot days will be up to three times (CMIP5, RCP 4.5) respectively four times (CMIP5, RCP 8.5) higher than under current climate conditions |
| Prague - Heat stress | Number and intensity of hot days have considerably increased in the last three decades.<br>Annual average intensity of the UHI effect in Prague in the period 1961-2012 was 2.2°C (June/July 2.4°C).<br>Annual average intensity of the UHI effect increasing in last years, especially during summer months, almost by 0.5°C | Business-as-usual scenario<br>• No specific measures | Nearly certain that there will be more frequent hot extremes in the second half of the 21st century. |
| Prague - Flood risk | Flood risk to the city (buildings, infrastructure (including Prague metro), businesses, public health, environment and historical heritage | Non-structural measures:<br>• Disaster response management<br>• Risk transfer tools<br>• Monitoring<br>• Management<br>Structural measures:<br>• Improving flood defences (engineering) | According to future climate projections, risks are likely to increase.<br>The Czech Republic is one of the countries most threatened by future floods in terms of extent and cost of possible damage, and it is therefore absolutely crucial to invest in adaptation and flood protection measures (Rojas et al. 2013). |
| Copenhagen - Coastal protection | Coastal flooding | Current coastal protection | Very high increase of risk due to sea level rise<br>Absolute mean sea level changes for Denmark, 1986-2005 to 2081-2100 in meter (Olesen et al. 2014)<br>• RCP2.6 = 0.34 (0.1-0.6)<br>• RCP4.5 = 0.43 (0.2-0.7)<br>• RCP6.0 = 0.44 (0.2-0.7)<br>• RCP8.5 = 0.61 (0.3-0.9) |

| Case study | Current risk/s | Current protection | Climate change effects |
|---|---|---|---|
| Copenhagen - Cloudbursts | Pluvial flooding | Current sewer system | Moderate increase in precipitation intensity (Olesen 2014)<br>• Annual average:<br>- RCP2.6 = 1.5 (+/-4.6)<br>- RCP8.5 = 6.9 (+/-6.1)<br>• Winter:<br>- RCP2.6 = 3.1 (+/-7.9)<br>- RCP8.5 = 18.0 (+/-12.0)<br>• Spring:<br>- RCP2.6 = 3.7 (+/-11.1)<br>- RCP8.5 = 10.7 (+/-12.6)<br>• Autumn:<br>- RCP2.6 = 0.8 (+/-7.2)<br>- RCP8.5 = 10.2 (+/-10.9) |

| Case study | Current risk/s | Current protection | Climate change effects |
|---|---|---|---|
| Kalajoki river basin - Flood risk | River flooding especially during the spring and low discharge in dry periods | Non-structural measures:<br>• Operational flood protection activities<br>• Land-use planning<br>• Guidelines for building: lowest building levels, regulations related to bridges and culverts<br>• Flood modelling, forecasting and warning<br>• Flood risk mapping<br>• Evacuation and emergency planning<br>• Emergency rehearsals<br>• Preparedness of landowners and citizens<br>• Flood documentation<br>Structural measures (floods, human settlements and infrastructure):<br>• Flood embankments to protect households and cultural sites along the main channel<br>• Embankments to protect agricultural land (about 70 km) along the main channel<br>• Dredging of the river channel and submerged weirs<br>• Hydropower plants/dams<br>• Water level regulation of natural lakes<br>• Water level regulation of artificial reservoirs | Flood risk with 100-year return period is projected to decrease on average 17 % in 2010–2039 and 18 % in 2070–2099.<br>Differences between different climate scenarios remain large; the range of projected changes was -28% – (-7.4%) in 2010–2039 and -32% – +1.3% in 2070–2099.<br>Floods in other seasons than spring are expected to become more common.<br>Higher winter discharges may increase risk for frazil ice dams. |

| Case study | Current risk/s | Current protection | Climate change effects |
|---|---|---|---|
| Kalajoki river basin - Water quality | River basin ecology: nutrient loads due to agricultural sector | Some measures to control nutrient loading:<br>• Buffer zones<br>• Constructed wetlands<br>• Controlled drainage<br>• Optimal fertilization | Increasing nutrient load from agricultural sector<br>Temperature increase by 1.6 °C until 2060 (SRES A1B).<br>Increasing evapotranspiration by 14% due to temperature increase<br>As the result of only slight precipitation increase and higher evapotranspiration increase, the annual discharge is decreasing on average by 5% (SRES A1B) in Kalajoki watershed.<br>The decrease in runoff and discharge is the main factor explaining the changes in nutrient loading. |
| Holstebro | River and pluvial flooding | Regulating the watercourse<br>Assessing sewers (non-structural measure, see BASE D6.1 table 1)<br>Climate adapted public buildings, when they are renovated (structural measure)<br>Including flooding related prevention in the local planning process (non-structural measure)<br>Co-operations on physical measures to delay water upstream Holstebro city (non-structural measure) | Climate change increases flood risk (2081-2100, reference period 1986-2005):<br>• RCP2.6: Average annual precipitation increases by 1,6%<br>• RCP8.5: Average annual precipitation increases by 6,9%<br>Flooding problems will not be experienced 'too often' (Holstebro Municipality 2014a) |
| Kalundborg | Fluvial flooding | | Expected effects are based on climate projections for Denmark (IPCC AR4 A2, until 2090):<br>• Winter precipitation increases by 43 %<br>• Summer precipitation decreases by 15 %<br>• Number of extreme precipitation events increases by 20 %<br>• No significant change in groundwater level in the case study area |

| Case study | Current risk/s | Current protection | Climate change effects |
|---|---|---|---|
| Venice | Damage to buildings in the historic centre of Venice due to coastal flooding | In 26% of residential and 33% of commercial buildings some private protection measures already have been implemented.<br>Further 32% of residential and 18% of commercial buildings adapted their units by raising floor levels. | Increase of global mean sea level by 2081 to 2100 (compared to 1986–2005), medium confidence (WGIII AR5 Chapter 5):<br>• RCP2.6: 0.29m to 0.55m<br>• RCP4.5: 0.36m to 0.63m<br>• RCP6.0: 0.37m to 0.64m<br>• RCP8.5: 0.48m to 0.82m<br>Low confidence on projected regional changes (Slangen et al. 2012; WGI AR5 Section 13.6)<br>With increasing sea levels, current periodic flooding of the historic centre will intensify (both with frequency & level). |
| Alentejo | • Water scarcity<br>• Drought<br>• Desertification | • Water Retention Landscape of Tamera<br>• Alqueva dam<br>• Farm irrigation lakes<br>• Farmers' capacity to adapt | Until the end of the century compared to reference period:<br>• Average annual temperature increases by 1.5ºC to 3.5ºC<br>• Average annual precipitation decreases by 15% to 25%<br>• Number of heavy precipitation events in the winter increases |
| South Aveiro Coast | • Coastal flooding<br>• Coastal erosion | • Yearly beach nourishment<br>• Longitudinal seawall in Vagueira<br>• Existing groins | • Sea water level rise by 0.6 Meters until 2100<br>• Increased number and intensity of extreme weather events<br>• Increased coastal erosion |
| Cascais | Urban fluvial flooding | • Separate sewage and fluvial water collection systems<br>• Green corridors (under construction) | Increase in number and probability of<br>• Heavy precipitation events<br>• Storm surges<br>• Cloudbursts |

| Case study | Current risk/s | Current protection | Climate change effects |
|---|---|---|---|
| Tagus Water District - Madrid | Hot and dry summers and cool winters<br>Irregularity of the inter-annual rainfall<br>Sectors and policy fields especially affected:<br>• Health and Social Policies<br>• Biodiversity & Ecosystems<br>• Disaster management | Non-structural measures:<br>• Awareness raising<br>• Disaster response management<br>• Risk transfer tools<br>Structural measures:<br>• Water conservation<br>• Water saving measures<br>• Ground water management<br>• Water technology<br>• Measures to minimise exposure to diseases | Climate Change will increase effects of existing risks in following sectors, policy fields:<br>• Water Management<br>• Human health<br>• Agriculture<br>• Human settlements and infrastructure<br>• Biodiversity and ecosystems |
| Doñana | Water scarcity<br>Salinity<br>Increased invasive species and pests<br>Irregularity of inter-annual rainfall<br>Sectors and policy fields especially affected:<br>• Agriculture<br>• Biodiversity & Ecosystems | Non-structural measures:<br>• Awareness raising<br>Structural measures:<br>• Water conservation<br>• Water saving measures<br>• Water technology | Climate Change will increase effects of existing risks<br>• Decreased water availability<br>• Increased water salinity<br>• Higher temperatures<br>• Reductions of water stored<br>• Heavy rains and higher deposits appearance<br>Sectors and policy fields especially affected:<br>• Agriculture<br>• Domestic use of water<br>• Biodiversity & Ecosystems |

| Case study | Current risk/s | Current protection | Climate change effects |
|---|---|---|---|
| Rotterdam – Fluvial flooding | Areas protected by the dike system:<br>• Residential sector<br>• High number of fatalities<br>• High economic damages<br>Areas not protected by the dike system:<br>• Low lying nature areas<br>• Agricultural sector<br>• Urban areas<br>• Residential sectors<br>• Shipping sector<br>• Damage to household belongings and interiors<br>• Failure of business processes<br>• Environmental damage | • Dikes<br>• Storm surge barrier<br>• One room for the river measure | • High Increase of flood risk in the steam scenario (fast CC, fast economic development)<br>• Slower increase in flood risk in the rest scenario (moderate CC, low economic development) |

| Case study | Current risk/s | Current protection | Climate change effects |
|---|---|---|---|
| Cornwall | Skin cancer is a significant health risk in Cornwall, due to climatic and social factors.<br>The south west of England currently experiences the highest incidence of both malignant and non-malignant melanoma in the UK (South West Health Observatory 2013), although there is no Cornwall specific data on skin cancer incidence. | There are a number of UK-wide public health campaigns aimed at educating and informing the public on how to reduce their individual risk of excessive UV exposure.<br>These initiatives are employed and/or are applicable at the local level (Cornwall) and include:<br>• SunSmart<br>• Met Office UV index<br>• „Saving our skins" toolkit<br>• General behaviour change<br>Analysis in the context of BASE focuses on SunSmart. | Increases in UV flux due to changing climate and prolonged exposure will likely increase the risks of both melanoma and non-melanoma skin cancers<br>Predicted reductions in cloud cover, the uncertainty around ozone depletion levels and behaviour change (> exposure), may all interact to result in a greater skin cancer incidence.<br>This is of particular importance in Cornwall, UK, given its popularity as a holiday destination. The south west also has a higher incidence of skin cancers anywhere in the UK where the UV intensity is higher, compared to the north of the country (by ~25%) (SWPHO 2014).<br>Additional risks of adapting to this increased UV flux (e.g. via avoiding strongest UV, applying sun protection) may have secondary impacts, if it inhibits the production of vitamin D (i.e. the benefits of UV exposure).<br>But despite predicted climate change effects on UV radiation, the critical factors affecting human exposure are lifestyle and behaviour (O'Hagen et al 2011). |

| Case study | Current risk/s | Current protection | Climate change effects |
|---|---|---|---|
| Leeds - Sustainable drainage | Fluvial flooding:<br>• Risk to residential and commercial properties, transport, community facilities and infrastructures, environment, cultural heritage, among others | Until 2014 mainly non-structural measures<br>• Awareness raising<br>• Disaster response management<br>• Monitoring and management<br>• Land use planning (i.e. risk zoning)<br>Implementation of Flood Alleviation Scheme of grey infrastructure started in 2014<br>Structural measures (existing or recommended)<br>• Improving flood defences (engineering)<br>• Flood resilient infrastructure<br>• Giving space to rivers (some in current grey infrastructure scheme)<br>• Improving drainage (by Yorkshire Water) | Increase in flood risk in nearly all affected sectors.<br>The UKCP09 central estimate gives projections of peak river flow increase of up to 10% by 2025, 15% from 2025 - 2055 and 20% beyond 2055.<br>The risk of fluvial flooding in Leeds is expected to increase the greatest during a 5% AEP flood (Environment Agency 2010).<br>These figures suggest that a current day 1 in 200 year event (0.5% AEP) will become a 1 in 75 year event (1.3% AEP) in 100 years' time (PAR 2013). |
| Leeds – Ecosystem-based adaptation | See Leeds - Sustainable drainage | See Leeds - Sustainable drainage | See Leeds - Sustainable drainage |
| Leeds - Infrastructure | See Leeds - Sustainable drainage | See Leeds - Sustainable drainage | See Leeds - Sustainable drainage |
| South Devon Coast - Railway | Storm surge risk to railway line | Existing low defences | Projected increases in sea level rise from UKCIP (2009) under low emissions scenarios suggest that minimum sea level rise could be 40 cm and up to 58.9 cm under a high emissions scenario by 2080.<br>Dawson (2012, p176) calculates that for every historical 0.05m rise in sea level, line restrictions (reduced service or line closure) increased by on average 7%. |

| Case study | Current risk/s | Current protection | Climate change effects |
|---|---|---|---|
| South Devon Coast - Fluvial flooding | Flooding of commercial and residential properties | None | Increases in the risk of extreme flooding events at Dawlish water for a low and medium emissions scenario (UKCIP):<br>• Until 2020: Flood risk 1/30<br>• 2020-2040: Flood risk 1/24<br>• 2040-2060: Flood risk 1/24<br>• 2060-2080: Flood risk 1/18 |
| Mental Health UK | The current scientific literature focuses on the impact of extreme events (i.e. flooding) have on mental health in both the short and long-term.<br>In addition to the impact of extreme events, it is important to understand the associations with more general changes in average climatic conditions in order to have a full understanding of the needs of any future adaptation strategy. | None – no specific adaptation measure in place for mental health | Local climate will be 2 to 3 °C warmer than now in winter and summer by 2050-2080<br>Longer periods of warm/hot and dry weather in spring and summer<br>Levels of precipitation will be similar but more concentrated in the winter months<br>Extreme weather events will become more frequent, including heat waves, storms, heavy rainfall, and cold spells<br>Main climate related health threats:<br>• Summer heat waves and droughts<br>• Flooding and associated mental health issues<br>• Interactions between air pollutants, pollen and higher temperatures<br>• Deterioration in food and water quality<br>• Increase in vector borne diseases |

## 2.2 Step 2: Adaptation options

**Objectives of adaptation**

- The primary objective, in most case studies, is the reduction of the primary climate change related risk.
- Sometimes this means the limitation to a certain target level (Prague heat stress, Rotterdam flood protection level), sometimes also risk minimisation (South Devon flood risk, Cascais flood risk).
- Often objectives are defined based on hazard levels, but sometimes also vulnerability-related objectives are mentioned, although not made explicit with quantitative targets (Madrid: heat stress reduction for the most vulnerable groups; Aveiro coast: coastal flooding avoidance for the population of Vagueira).
- However, economic considerations are only in some cases explicit in the objectives. In Rotterdam the objective is to find the most cost-effective pathway, in Prague an “efficient” management of flood risk is defined as the main aim.

**Baseline**

- Almost all case studies define a “business-as-usual” as baseline option, i.e. maintaining current protection levels and no investment in new measures.
- In the Jena case study no “business-as-usual” exists, as the three sub cases are new urban development areas. In this case a “typical” tar and gravel roof is used as a baseline in the CBA and compared to a green roof option. In the Jena MCAs no baseline is required and different bundles are compared to each other.
- Considering the aim of assessing existing protection measures, the Venice case studies define its baseline not as the current state of private protection but as a hypothetical “do nothing” scenario, assuming that no private protection would take place.

**Adaptation options**

Floods:

- Mainly structural measures aiming at the reduction of the flood hazard are analysed (dikes, sluices, private flood gates).
- Sometimes also non-structural hazard-related measures (room for the river, green water gardens, green corridors, flood water retention on agricultural land & compensation of farmers) are considered.
- Only few exposure- or vulnerability-related measures are considered (e.g. re-routing railway line at the South Devon coast would be an exposure-related measure, both the private protection measures in Venice and at the Dawlish Water can be considered as vulnerability-related measures as they reduce damage directly at the household level).
- Mainly public measures are analysed and only in a few cases also private measures are considered for the assessment (private flood protection in Venice, private flood gate in the South Devon river case study). In the Holstebro case study it is a combination of public intervention and private action: a public compensation payment to farmers to allow flood retention on their private land in combination with the construction of a dam that can withstand a 1/100-year event.

Heat stress/health:

- Most of the heat stress-related adaptation measures focus on hazard mitigation, i.e. reductions of heat stress levels (e.g. by the use of green roofs solutions, urban green spaces, trees, water elements, light-coloured pavements, etc.), some of them rather structural measures, some of them partly nature-based solutions (green spaces, trees, green roofs)
- Two vulnerability-related options are assessed: The heat warning system in Madrid, and the health campaign in Cornwall regarding UV-protection).
- In general public adaptation measures are assessed, e.g. bundles of adaptation options to reduce heat stress in the public area in the Jena sub-cases or the heat warning system in Madrid. Though, at least some potential private adaptation measures are evaluated, e.g. the green roof CBA in Jena primarily comparing private costs and benefits and considering public benefits rather as an add-on to these.

Ecosystem protection:

- The Czech "Green roof" case study considers pro-active measures, e.g. peatland & watercourse restoration and sustainable forest management, but also a more protective measure as for instance enlargement of protection areas. In this case study measures are bundled to different strategies (a green scenario, prioritizing nature protection, a red scenario, prioritising economic development, and a "shared-vision"-strategy.

Water quality:

- In the Kalajoki case study focussing on water quality different agro-environmental measures are considered. One of them trying to minimise the initial nutrient emission (optimal fertilisation), the other trying to hinder nutrients from entering the river (buffer zones, constructed wetlands, winter time vegetation cover, perennial grass, controlled drainage).

**Bundling of measures**

- Only few case studies assess single measures (Kalajoki case studies, Holstebro, Alentejo, to some degree also Rotterdam). The other case studies evaluate and compare different bundles of measures, e.g. Green roof, Jena, Copenhagen, Aveiro Coast. It seems that the bundling of measures is a necessity for successful adaptation for many types of risks. Therefore, assessing bundles of measures is often closer to real world decision-making processes in the field of climate change adaptation than comparing single adaptation measures.

**Table 2-3: Overview step 2: Adaptation options considered by BASE case studies**

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Timmendorfer Strand | Primary:<br>• Damage reduction by protecting human health and economic infrastructure<br>Secondary:<br>• Maintain tourism | No further coastal protection | • Coastal protection measure<br>• Finishing and landscaping-project, i.e. improvement of the beach promenade, two new boardwalks – established in the dunes - and recreational infrastructure, e.g. benches, playground | Coastal protection measure in combination with the finishing and landscaping-project |
| Green Roof | • Maintain a favourable state of local ecosystems<br>• Preserve natural ecosystem processes | Business-as-usual scenario to 2050<br>• No substantial climate and land use/land cover change<br>• No adaptation measures will be implemented (current strategy in the area)<br>• Ecosystem services to be provided at the same level as in the current landscape<br>• Regular management costs to remain at the current level | • Mainly ecosystem-based adaptation measures<br>• Sustainable forest management<br>• Peat land and water course restoration<br>• Enhancement of ecosystem protection, i.e. an enlargement of nature conservation zones | Bundling of adaptation measures (see before) for 3 strategies<br>Green scenario:<br>• Prioritising nature conservation<br>Red scenario:<br>• Prioritising economic development<br>Shared vision scenario:<br>• Sustainable economic development<br>• Maintaining level of nature conservation<br>• Focus on small-scale businesses and local production |

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Jena - Winzerberge | Heat stress reduction | No baseline option available as maintaining the current configuration of the site is not an option | 2 similar basic drafts (for details see section 6.3 in annex 3) complemented with the following measures:<br>(A) Use of small-crowned tree species (Sorbus intermedia „Brouwers“)<br>(B) Use of large-crowned tree species (Tilia cordata „Greenspire“)<br>(C) Use of ordinarily coloured cobblestones (albedo value of 0.3)<br>(D) Use of light-coloured cobblestones (albedo value of 0.5) | Alternative 1: Draft 1 + A & C<br>Alternative 2: Draft 1 + A & D<br>Alternative 3: Draft 1 + B & C<br>Alternative 4: Draft 1 + B & D<br>Alternative 5: Draft 2 + A & C<br>Alternative 6: Draft 2 + A & D<br>Alternative 7: Draft 2 + B & C<br>Alternative 8: Draft 2 + B & D |

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Jena - Inselplatz | Heat stress reduction | No baseline option available as maintaining the current configuration of the site is not an option | (A) Use of small-crowned tree species (Sorbus intermedia „Brouwers") <br> (B) Use of large-crowned tree species (Tilia cordata „Greenspire"/ Gingko Biloba) <br> (C) Use of ordinarily coloured cobblestones (albedo value of 0.3) <br> (D) Use of light-coloured cobblestones (albedo value of 0.5) <br> (E) Use of green roofs <br> (F) Use of façade greening <br> (G) Use of water element | Alternative 1 <br> • Existing trees: 14 <br> • Newly planted trees: 25x(A) <br> • Outward pavement: (C) <br> • Inward pavement: (C) <br> • Green roofs: 31% <br> • Façade greening: none <br> • Water element: none <br> Alternative 2 <br> • Existing trees: 14 <br> • Newly planted trees: 14x(A), 15x (B) <br> • Outward pavement: (C) <br> • Inward pavement: (D) <br> • Green roofs: 50% <br> • Façade greening: 5% <br> • Water element: about 40 m² (57 m x 0.7 m) <br> Alternative 3 <br> • Existing trees: 14 <br> • Newly planted trees: 4x(A), 27x (B) <br> • Outward pavement: (D) <br> • Inward pavement: (D) <br> • Green roofs: 70% <br> • Façade greening: 15% <br> • Water element: about 80 m² (80 m x 1 m) |

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Jena - Zwätzen | Heat stress reduction | No baseline option available as maintaining the status, i.e. using the site as grassland, is not an option | (A) Use of small-crowned tree species (Sorbus intermedia „Brouwers“)<br>(B) Use of large-crowned tree species (Tilia cordata „Greenspire“)<br>(C) Use of ordinarily coloured cobblestones (albedo value of 0.3)<br>(D) Use of light-coloured cobblestones (albedo value of 0.5)<br>(E) Use of green roofs<br>(F) Use of water elements | Alternative 1<br>• Newly planted trees: 127x(A), 25x(B)<br>• Sidewalks: (C)<br>• Recreational area: (C)<br>• Green roofs: 30%<br>• Water element: water gutters (width in inner area 0.5 m, width at Northern border 2 m)<br>Alternative 2<br>• Newly planted trees: 183x(A), 63x(B)<br>• Sidewalks: (D)<br>• Recreational area: (C)<br>• Green roofs: 50%<br>• Water elements: water gutters (width in inner area 0.5 m, width at Northern border 2 m), fountain 50 m²<br>Alternative 3<br>• Newly planted trees: 99x(A), 142x(B)<br>• Sidewalks: (D)<br>• Recreational area: (D)<br>• Green roofs: 70%<br>• Water elements: water gutters (width in inner area 0.5 m, width at Northern border 2 m), fountain 100 m² |
| Prague - Heat stress | Heat stress reduction | Current spatial plan of Prague | • Increase of green area<br>• Increase of water area | Increase of green area by 15%<br>Increase of water area by 3%, Increase of green area by 7%<br>Increase of green area by 7% |

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Prague - Flood risk | Efficient flood risk management | For the baseline strategy it is assumed that the flood protection is maintained on the same level as it was in 2002 before the great flood event | Structural measures (part of the flood control system (FCS), 2014)<br>• Fixed measures: 12.460 m<br>• Mobile measures 6.795 m<br>• Heavy mobile measures 130m<br>Non-structural measures, which are not included in the FCS are not considered for assessment<br>• Awareness raising<br>• Disaster response management<br>• Risk transfer tools<br>• Monitoring<br>• Management | |
| Copenhagen - Coastal protection | Mitigate risk from coastal flooding | Current protection level | • Dike<br>• Sluices | CBA:<br>• Adaptation solutions, i.e. combination of dike and sluices, are designed to withstand a high tide of 255 cm.<br>MCA:<br>• 5 variations of the adaptation solutions were developed, each one of them was developed by a group with a particular professional background |

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Copenhagen - Cloudbursts | Mitigate flood risk | No further investment in upgrading the sewers | • Sewage system<br>• Backflow valve in basements<br>• Surface adaptation | 1. Maintain sewage service level<br>2. Maintain sewage service level plus backflow valve in all basements<br>3. Maintain sewage service level plus backflow valve in all basements plus surface adaptation<br>4. Only backflow valve in all basements plus surface adaptation<br>5. Only backflow valve plus surface adaptation after the sewage system is upgraded |
| Kalajoki river basin - Flood risk | Reduce flood risk<br>Mitigate negative consequence<br>Promote preparedness for floods | Keep the current flood protection standards and risk levels<br>Development of current measures (capacity building, flood insurance, operational measures, current water regulation)<br>No additional measures | A selection of potential measure types that needed further analysis:<br>• Using agricultural land as floodplains<br>• Extended use of regulated lakes as water storage<br>• Improving summer flood preparedness in Hautaperä reservoir regulation<br>• Improving summer flood preparedness in lake Reisjärvi regulation<br>• Increasing the retention capacity of the river basin<br>• Permanent flood protection structures | As there are no single, feasible measures, which would solve the problem alone, combination of measures will be needed to achieve the objectives.<br>Analysis focuses on the prioritisation of single measures. |

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Kalajoki river basin - Water quality | Limit nutrient load | No additional measures | • Buffer zones (different slopes)<br>• Small constructed wetlands (different % of fields)<br>• Medium constructed wetlands (different % of fields)<br>• Large constructed wetlands (different % of fields)<br>• Winter time vegetation cover (different slopes)<br>• Perennial grass (different slopes)<br>• Controlled drainage<br>• Optimal fertilization | |

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Holstebro | Mitigate flood risk for the city | Current protection levels are maintained | 1. Widening of Storå at Storebro + increasing depth of Storå at the stretch below Storebro (structural)<br>2. Establishing bridge at overflow ramp (structural)<br>3. Increasing depth of Storå at the stretch upstream Østrbrogade to the allotments (structural)<br>4. High water level protection at Vigen (structural)<br>5. High water level protection of the Music Theatre (structural)<br>6. Extended watercourse routing in Lægård Bæk and Frøjk Bæk (structural)<br>7. Local dam to retain water east of Vandkraftsøen (structural)<br>8. Retaining water through decentral dam solutions (structural)<br>9. SMS flooding warnings to citizens (non-structural)<br>10. Citizen report portal (non-structural)<br>11. The farmer as water manager (structural (water retention, delaying, storing) and non-structural (economic incentives)[4] | The ‘farmer as water manager’ is a measure that would work in conjunction with the construction of a dam to retain water upstream.<br>The retention option analysed is designed to protect against 1/100-year events. We estimate the costs in the case of a 1000 year event. The associated costs equal the costs of a 100 year event without a dam. |

[4] This is the option analysed in the Holstebro case study.

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Kalundborg | | BAU | Predefined future strategies:<br>1. Laissez-faire<br>2. Gradual adaptation<br>3. Protection (pumps and dikes) | Visions identified by stakeholders:<br>1. Offshore dikes<br>2. Large dikes on the coast and land<br>3. Phasing out of vulnerable areas with human settlement during this century<br>4. Quicker conversion to natural areas (no temporary protection)<br>On the basis of the 4 visions 24 concrete adaptation solutions were defined |
| Venice | Primary objective:<br>• Reduction of damages from flooding on private real estate assets<br>Secondary objective:<br>• Maintaining the city as a living environment | No private protection measures at all | The measures for adapting existing buildings (wet or dry flood proofing):<br>• Changes in building materials and techniques<br>• Aiming at protecting living environments from being flooded (raising floor levels, small barriers, protection of building elements against intrusion of salt water, with protective construction elements (vasca))<br>• Preventing saline water from penetrating into brick walls by physical barriers introduced into walls<br>In the public space, pavement levels have been raised as far as possible in order to improve pedestrian circulation during flood events (no costs available – excluded from the analysis). | 1. Present state of adaptation (existing private protection)<br>2. Small adaptation measures (punctual insulation measures, raising of floor levels, etc., wet flood proofing)<br>3. Full impermeabilisation of buildings (dry flood proofing, vasca)<br>4. Only floor level raising |

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Alentejo | Capture and store water in the landscape<br>Create a productive and diverse landscape<br>Stop and reverse soil erosion/loss and desertification in the Alentejo | Business-as-Usual scenario to 2050<br>• Progressive climate and land use/land cover change<br>• No adaptation measures will be implemented except payments to farmers for loss of productivity (current strategy in the area)<br>• Ecosystem services to be provided with progressively lower levels than in the current landscape<br>• Management costs to increase progressively as water scarcity, soil loss, tree mortality and desertification increases | Water retention landscape (Lakes of Tamera)<br>Other measures were identified, but not studied in quantitative economic terms, such as dams, farm lakes, keyline, swales, crop diversification, use of adapted species, improvement of species, etc. | No bundling of measures was considered |
| South Aveiro Coast | Hold the coast line and maintain existing land uses<br>No retreat option was considered | Business-as-Usual scenario to 2050<br>• No substantial climate and land use/land cover change<br>• Beach nourishment is used when necessary and in a responsive way to extreme events<br>• Ecosystem services to be provided at the same level as in the current landscape | • Artificial beach nourishment<br>• Sea walls<br>• Groins<br>• Detached breakwater<br>• Palisades and walkways on the dunes<br>• Reinforcement of dune systems | For each of the 5 stretches of the coastline under research a different set of adaptation options was considered according to the specific conditions and socio-economic-geographical- environmental contexts for adaptation; See annex 3 for specific details. |

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Cascais | Reduce current level of flood risk for 1 in 100-year return flood event by 50% | Business-as-Usual scenario to 2050<br>• No substantial climate and land use/land cover change;<br>• No adaptation measures will be implemented (current strategy in the area)<br>• Ecosystem services to be provided at the same level as in the current landscape<br>• Regular management costs to remain at the current level | • Green roofs<br>• Rain water gardens<br>• Rain water harvesting<br>• Green corridors and rehabilitation of Cascais streams<br>• Land use change in high risk flood prone areas | No |
| Tagus Water District - Madrid | Reduce the vulnerability of society to the effect of heat waves | Ambition level of the baseline strategy:<br>• Most of the stakeholders try to maintain current protection levels seen from a single sector point of view. The case study analyses trade-offs and synergies between sectors to ensure a more resilient society under future climate conditions.“ | • Green roofs<br>• Well defined and efficient Heat Health Warning System | 4 types of green roofs coverage over the residential and commercial area of Madrid<br>• 5%,<br>• 20%<br>• 50%<br>• 100%<br><br>Heat Warning System<br>• Redefinition of the critical temperature, from 36.5ºC to 34ºC in the baseline scenario (2004-2009)<br>• Adjustment of critical temperature, attributable risks for health and displaced mortality rate over time (2020-2100) to take into account acclimatisation processes |

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Doñana | Reduce the vulnerability of the Doñana region to water scarcity and high temperatures | Maintain current protection levels | Technological measures:<br>• Water recirculation and reutilization<br>• Increased technical efficiency of the irrigation systems.<br>• Laser levelling<br>• Integrated production) were also fully supported by the administration<br>Organizational measures<br>• Local monitoring<br>• Accurate, accessible and useful water information at different scales<br>Governance measures<br>• Improve the coordination between institutions<br>• Increase scientific research<br>• Farmer training<br>• Technical advice were governance options | |
| Rotterdam – Fluvial flooding | Meet flood protection targets | Dike reinforcement to keep current protection levels | • Room for the River small 1<br>• Room for the River small 2<br>• Room for the River 3<br>• Room for the River 4<br>• Water storage lake Grevelingen<br>• Full closure with dams & sluices<br>• Channel deepening<br>• Combination of 2+3 | The four "room for the river" measures are actually a bundling of small green adaptation measures. |

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Cornwall | To reduce the incidence of skin cancers in Cornwall by promoting positive messages of behaviour | No public health campaign | Public health campaigns:<br>• Met Office UV index<br>• SunSmart<br>• „Saving our skins“ toolkit<br>• General behaviour change | |
| Leeds - Sustainable drainage | Primary:<br>• Reduce flood risk<br>Secondary:<br>• Provision of co-benefits to the area | Current flood risk with existing non-structural adaptation measures without the grey infrastructure currently being built<br>Impacts of current flood risk compiled and estimated for the Aire catchment and the Leeds district at an Annual Exceedance Probability (AEP) of 5%, 1.3%, 1%, and 0.5% and 0.1%<br>Ambition level is to maintain current risk levels but assuming that with climate change this risk will rise.<br>The baseline does not include planned adaptation. | • Detention basins<br>• Filter drains<br>• Green roofs - extensive sedum<br>• Infiltration basins<br>• Infiltration trenches<br>• Permeable paving<br>• Rainwater harvesting<br>• Retention ponds<br>• Soakaways<br>• Swales<br>• Water butts<br>• Wetlands<br>• Urban trees | Three adaptation measures explored separately in the Leeds case study, which should be bundled for optimum flood risk reduction. |
| Leeds – Ecosystem-based adaptation | See Leeds - Sustainable drainage | See Leeds - Sustainable drainage | Broadleaf woodland planting | See Leeds - Sustainable drainage |

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Leeds - Infrastructure | See Leeds - Sustainable drainage | See Leeds - Sustainable drainage | In 2014 new wall and embankment at Woodlesford completed for 1 in 200 year protection (downstream from city centre)<br>In the city centre for a 1 in 75 year protection (currently being implemented:<br>• Replacing existing weirs with moveable weirs at Crown Point and Knostrop Cut<br>• Removing Knostrop cut (island) so Canal and River Aire merge<br>Increasing the height of existing river walls; building new walls, embankments and terracing | See Leeds - Sustainable drainage |
| South Devon Coast - Railway | Make the South West of England's railway infrastructure and related economic benefits less vulnerable to storm events at the Dawlish coast. | Business-as-usual option<br>• Maintaining existing sea defences, conducting repairs to damage to the rail infra-structure, cliffs and sea wall from storm events) | • Strengthening and heightening the sea wall<br>• Stabilising the cliffs through wire netting and bolting<br>• Measures to mitigate the erosion of beech material<br>• Reroute the railway | 1. Strengthen the existing sea defences<br>Strengthening and heightening the sea wall, stabilising the cliffs through wire netting and bolting, measures to mitigate the erosion of beech material (e.g. improved groynes)<br>2. Reroute the railway inland away from the Dawlish coast<br>Several proposed options, the cheapest of which is using the old Teign Valley line (Network Rail 2014) |
| South Devon Coast - Fluvial flooding | Minimise the risk of flooding to properties bordering Dawlish Water | Business-as-usual option<br>• No intervention to protect the 50 at risk properties | | 1. Installation of domestic flood gates at 50 at risk properties<br>2. Installation of sluice gates up stream to hold back flood water |

| Case study | Objective of adaptation | Baseline option | Adaptation measures | Bundling of measures |
|---|---|---|---|---|
| Mental Health UK | To improve mental health in the UK | Current practice – medication | The results of our analysis suggest that prescription demand will fall under climate change – so this implies that the autonomous response of the system will be to reduce drug prescriptions. | |

## 2.3 Step 3: Evaluation approaches & evaluation criteria applied

**Evaluation methods**

- Table 2-4 gives an overview of the different evaluation methods applied in the BASE case studies differentiated by risk categories.
- Mostly CBAs are carried out, in particular in the case studies dealing with flood risk.
- CEA is applied in a water quality-related case study (where the benefit is difficult to evaluate in monetary terms), but also for flood retention measures (costs for a certain amount of discharge retention).
- MCAs are conducted in case studies looking at flood risk reduction (complementary to CBA, considering other criteria difficult to assess in monetary terms) but also in the heat stress-related case studies (where heat stress reductions are difficult to monetise).
- Though there are also (at least partial) heat stress-related CBAs (Madrid, Jena) and a CBA assessing adaptation measures tackling ecosystem degradation (Green roof).
- PBCA is applied in a comprehensive way in the Cascais and parts of the approach in the Alentejo case studies.

**Table 2-4: Assessment approaches applied by BASE case studies**

| | CBA | CEA | MCA | PBCA |
|---|---|---|---|---|
| Flooding & Coastal erosion | Kalajoki<br>Copenhagen<br>Rotterdam<br>Aveiro Coast<br>South Devon Coast<br>Leeds<br>Timmendorfer Strand<br>Prague | Cascais<br>Holstebro | Kalajoki<br>Copenhagen<br>Rotterdam<br>Aveiro Coast<br>Cascais (Participatory) | Cascais |
| Heat stress & Health | Jena<br>Madrid | | Jena | |
| Water scarcity | Alentejo<br>Doñana | | Doñana | Alentejo |
| Water quality | | Kalajoki | | |
| Ecosystem degradation | Green roof | | | |

**Evaluation criteria:**

- In the following we define cost criteria as those criteria which are related to the construction, installation, implementation, operation and maintenance of measures (considering that some adaptation option might also have lower costs than the baseline), while benefit criteria are those which describe the effect of the measure related to the primary or secondary objective of adaption and further side-effects (considering that some measures might have negative effects on some of these criteria).

Costs:

- On the cost side in particular the investment costs of construction or installation of measures, re-investment costs for renewing measures as well as the operation and maintenance costs are considered.
- In some cases also the negative environmental impacts of the adaptation measures are considered (e.g. costs influenced by the provision of ecosystem services such as sediment and nitrogen retention in the Green roof case study or environmental losses caused by the measures in the Doñana case study). Also the Leeds infrastructure case study includes negative side effects of the measures.
- Transaction costs, i.e. costs associated with the design, appraisal and implementation of measures (Williamson 1999; Birner & Wittmer 2004; McCann et al. 2005) are considered e.g. in the Leeds case study. Costs related to conflicts with other water users, as mentioned in the Doñana case study can also be considered as transaction costs. Furthermore, many MCA case studies include criteria such as technical, financial and juridical feasibility, which can also be defined as transaction costs (Copenhagen, Kalajoki flood risk).
- Costs related to the negative impact of adaptation on land values are considered in the Doñana case.
- Depending on the nature of the adaptation options (public or private) it is also an important question, who is bearing the costs of adaptation: Is it a public or private investment, or are private house or landowners compensated by public authorities?

Benefits:

- In all case studies the main benefit component is related to the primary aim of adaptation: the benefits of risk reduction (i.e. the avoided damages or negative effects due to climate change). Depending on the focus of the case study this can be avoided flood losses, reduced heat stress levels and related reductions in health effects, reduced ecosystem degradation or a reduction in nitrogen pollution.
- In some cases these benefits are measured in monetary terms (i.e. reduced flood damage), in other cases they are measured in non-monetary units (reduction of the heat stress level in Jena, or reduction of P concentration in the Kalajoki water quality study).
- Many case studies concentrate on the direct, tangible damages avoided (Copenhagen, Kalundborg, South Devon river flooding, Venice).
- Others also try to include indirect and intangible effects. E.g. in the Rotterdam case also (avoided) business interruption losses and indirect losses, i.e. induced losses to the wider economy are considered. The South Devon railway case study includes the avoided compensation payments to train operators, the avoided losses to freight transport and commuters as well as the wider economic effects of traffic interruption.
- Some case studies try to include intangible benefits in monetary terms (e.g. reduced mortality in the Madrid, Leeds and Rotterdam cases, reduced skin cancer cases in the Cornwall case study, improved ecosystem services in the Green roof and Leeds case, reduced environmental and cultural flood damages in the Prague case study) in many other case studies such environmental and health impacts are included in non-monetary terms (Jena, Kalajoki, Copenhagen, Rotterdam, Cascais).

- Many case studies also include side effects, i.e. effects not related to the primary objective of adaptation. This could be environmental effects (e.g. Leeds, Rotterdam) but also side effects in other economic sectors, e.g. tourism (Green roof, Kalajoki, Copenhagen), fishing (Kalajoki), shipping (Rotterdam), hydropower (Kalajoki) or other societal benefits, such as amenity value and architectural quality (Jena).

**Table 2-5: Assessment criteria used by BASE case studies**

| Criteria | Scale | Case studies |
|---|---|---|
| **Cost-related** | | |
| Investment, reinvestment costs | Monetary | Timmendorfer Strand, Green roof, Jena Winzerberge, Jena Inselplatz, Jena Zwätzen, Prague Flood, Copenhagen Coastal, Kalajoki river basin Water quality, Kalundborg, Alentejo, South Aveiro Coast, Cascais, Tagus Water District – Madrid Heat Warning, Tagus Water District – Green roof, Doñana, Rotterdam, Leeds Sustainable drainage, Leeds EBA, Leeds Infrastructure, South Devon Coast Railway, South Devon Coast Fluvial flooding |
| Maintenance, operational costs | Monetary | Timmendorfer Strand, Green roof, Jena Winzerberge, Jena Inselplatz, Jena Zwätzen, Prague Flood, Copenhagen Coastal, Cascais, Tagus Water District – Madrid Heat Warning, Tagus Water District – Green roof, Rotterdam, Leeds Sustainable drainage, Leeds EBA, Leeds Infrastructure, South Devon Coast Railway |
| Cost (one-off, recurring) | Monetary | Copenhagen Cloudbursts, Kalajoki river basin Flood, Venice |
| Rehabilitation costs | Monetary | Jena Inselplatz |
| Transaction costs | Monetary | Alentejo, South Aveiro Coast, Cascais |
| Consultancy costs | Monetary | Alentejo |
| Expropriation costs | Monetary | South Aveiro Coast |
| Provision of ecosystem services | Monetary | Green roof |
| Compensations for using agricultural land as retention area | Monetary | Holstebro, Leeds EBA |
| Negative side effects | Monetary | Leeds Infrastructure |
| Costs of a skin cancer health campaign | Monetary | Cornwall |
| Cost (one-off, recurring) | Qualitative | Copenhagen Coastal |
| Implementation related aspects (effort, complexity) | Qualitative | Copenhagen Coastal, Cascais |
| Feasibility | Qualitative | Copenhagen Coastal, Kalajoki river basin Flood |
| Reduction of land value | Qualitative | Doñana |
| Loss of economic activity | Qualitative | Doñana |

| Criteria | Scale | Case studies |
|---|---|---|
| Environmental losses | Qualitative | Doñana |
| Increase of user conflicts | Qualitative | Doñana |
| **Benefit-related** | | |
| Flood damages avoided | Monetary | Timmendorfer Strand, Prague Flood, Copenhagen Coastal, Copenhagen Cloudbursts, Holstebro, Kalundborg, Venice, South Aveiro Coast, Rotterdam, Leeds Sustainable drainage, Leeds EBA, Leeds Infrastructure, South Devon Coast Railway, South Devon Coast Fluvial flooding, Kalajoki river basin Flood |
| Maintenance efforts avoided | Monetary | South Devon Coast Railway, Tagus Water District – Green roof |
| Casualties avoided (heat) | Monetary | Tagus Water District – Madrid Heat Warning, Leeds Sustainable drainage |
| Energy cost savings | Monetary | Jena Inselplatz, Tagus Water District – Green roof, Leeds Sustainable drainage |
| Carbon footprint reduction (sequestration & emission reduction) | Monetary | Jena Inselplatz, Alentejo, Leeds Sustainable drainage, Leeds EBA, Tagus Water District – Green roof |
| Stormwater management savings | Monetary | Jena Inselplatz |
| Water retention savings | Monetary | Tagus Water District – Green roof |
| Stormwater fee savings | Monetary | Jena Inselplatz |
| Air quality improvement | Monetary | Leeds Sustainable drainage |
| Water use savings | Monetary | Leeds Sustainable drainage |
| Provision of ecosystem services | Monetary | Green roof, Leeds sustainable drainage, Leeds EBA |
| Habitat creation | Monetary | Jena Inselplatz, Leeds EBA |
| Improvement of water quality | Monetary | Alentejo, Leeds Sustainable drainage, Leeds EBA |
| Reduction of erosion | Monetary | Leeds EBA |
| Recreational aspects | Monetary | Timmendorfer Strand, Leeds Sustainable drainage, Leeds PES |
| Aesthetic aspects | Monetary | Leeds Sustainable drainage, Leeds EBA |
| Compensations avoided | Monetary | South Devon Coast Railway |
| Private costs of interruption avoided | Monetary | South Devon Coast Railway |
| Change of market value (property, land) | Monetary | Timmendorfer Strand, Alentejo, Leeds EBA |

| Criteria | Scale | Case studies |
|---|---|---|
| Indirect economic effects avoided | Monetary | South Devon Coast Railway |
| Cases of skin cancer and their treatment costs | Monetary | Cornwall |
| Reduction of phosphorus load | Quantitative | Kalajoki river basin Water quality |
| Impact on flood risk | Quantitative | Kalajoki river basin Flood, |
| Casualties avoided (flood) | Quantitative | Rotterdam |
| Number of people affected | Quantitative | Rotterdam |
| Risk to life avoided | Quantitative | Leeds |
| Health damages avoided | Quantitative | Leeds, Tagus Water District |
| Heat stress level | Quantitative | Jena Winzerberge, Jena Inselplatz, Jena Zwätzen, Prague Heat |
| Impact on shipping | Quantitative | Rotterdam |
| Number of parking lots | Quantitative | Jena Winzerberge |
| Flood damages avoided | Qualitative | Timmendorfer Strand |
| Ecological/environmental impact | Qualitative | Kalajoki river basin Flood, Rotterdam, Copenhagen Coastal |
| Socio-economic impact | Qualitative | Kalajoki river basin Flood |
| Commercial impacts | Qualitative | Copenhagen Coastal, Alentejo |
| Touristic impacts | Qualitative | Copenhagen Coastal, Alentejo, South Aveiro Coast |
| Recreational aspects | Qualitative | Timmendorfer Strand, Copenhagen Coastal |
| Aesthetic aspects | Qualitative | Copenhagen Coastal |
| Amenity value | Qualitative | Jena Winzerberge, Jena Inselplatz, Jena Zwätzen |
| Architectural quality | Qualitative | Jena Winzerberge, Jena Inselplatz, Jena Zwätzen |
| Possible risks/uncertainties | Qualitative | Kalajoki river basin Flood |
| Socio-economic impact | Qualitative | Doñana |
| Environmental impact | Qualitative | Doñana |

**Table 2-6: Overview step 3: Evaluation approaches of BASE case studies**

| Case Study | Evaluation criteria | Method(s) | Weighting approach (only for MCA) | Remarks |
|---|---|---|---|---|
| Timmendorfer Strand | Costs:<br>• Investment and maintenance costs (coastal protection measure + finishing and landscaping measure)<br>Benefits:<br>• Avoided flooding damages (partially monetary: avoided damage per event, partially qualitative)<br>• Change of recreational function, tourism: (partially monetary: change per year, partially qualitative)<br>• Income effects (costs/benefits) on local tourism infrastructure<br>• Turnover of restaurant owners<br>• Travellers to community -> spendings per day<br>• Change of property prices | CBA | | |

| Case Study | Evaluation criteria | Method(s) | Weighting approach (only for MCA) | Remarks |
|---|---|---|---|---|
| Green Roof | Costs:<br>• Investment costs (peat-land restoration)<br>• Maintenance and operation costs (sustainable forest management)<br>• Investment cost of infrastructure (paths for tourists and foresters, tourist information facilities, etc.)<br>• Costs influenced by the provision of ecosystem services (sediment dredging, nitrogen removal)<br>Benefits:<br>• Resulting from the provision of ecosystem services, i.e. carbon sequestration, hydropower production<br>• Resulting from the implementation of adaptation measures, i.e. timber sales, sales of services related to hunting | Scenario analysis<br>CBA | | Consideration of uncertainty at the stage of scenario and ecosystem services modelling:<br>• Ecosystem services modelled separately for two climate projections, RCP4.5 and RCP 8.5. Resulting differences have been taken into account in two ecosystem models which require climate parameters, nitrogen retention and hydropower production.<br>• All model parameters have been subject to a thorough review of scientific sources. Still there are a few unavoidable sources of uncertainty regarding some ecological parameters required by the models (soil parameters, carbon pools, nitrogen loading, erosion coefficients, etc.). Since for some of them only a single data source (map) is available, the degree of uncertainty originating from this point cannot be quantified.<br>Consideration of uncertainty at the stage of cost-benefit analysis:<br>• Calculation of costs and benefits for the mean, minimum and maximum marginal values of individual ecosystem services and management approaches (based on literature review) |

| Case Study | Evaluation criteria | Method(s) | Weighting approach (only for MCA) | Remarks |
|---|---|---|---|---|
| Jena - Winzerberge | Costs:<br>• Net present costs, i.e. discounted investment, reinvestment, maintenance costs<br>Benefits:<br>• Heat stress potential<br>• Number of parking lots<br>• Architectural quality<br>• Amenity value | MCA | Point Allocation | |
| Jena - Inselplatz | MCA<br>Costs:<br>• Net present costs, i.e. discounted investment, reinvestment, maintenance costs<br>Benefits:<br>• Heat stress potential<br>• Architectural quality<br>• Amenity value<br>CBA<br>• Costs<br>- Investment, reinvestment, maintenance, rehabilitation costs<br>• Benefits<br>- Stormwater fee savings<br>- Energy cost savings<br>- Stormwater management infrastructure savings<br>- Carbon sequestration<br>- Habitat creation | MCA<br>CBA | Point Allocation | |

| Case Study | Evaluation criteria | Method(s) | Weighting approach (only for MCA) | Remarks |
|---|---|---|---|---|
| Jena - Zwätzen | Costs:<br>• Net present costs, i.e. discounted investment, reinvestment, maintenance costs<br>Benefits:<br>• Heat stress potential<br>• Architectural quality<br>• Amenity value<br>• Marketing potential | MCA | Point Allocation | |
| Prague - Heat stress | Effectiveness of keeping heat stress potential below an URBAHT score of 6 (moderately elevated heat stress level) – adaptation tipping point | Adaptation Pathway approach | | |
| Prague - Flood risk | Costs:<br>• Construction costs<br>• Installation costs (mobile protection)<br>• Maintenance costs<br>Benefits:<br>• Flood damage avoided (residential, infrastructure, industry, equipment, evacuation, environment, cultural heritage, cleaning costs) | CBA | | |

| Case Study | Evaluation criteria | Method(s) | Weighting approach (only for MCA) | Remarks |
|---|---|---|---|---|
| Copenhagen - Coastal protection | CBA:<br>• Costs:<br>- Investment costs<br>- Reinvestments costs<br>- Operation costs<br>- Maintenance costs<br>• Benefits:<br>- Avoided flood damages<br>MCA:<br>• Implementation:<br>- Implementation costs<br>- Running and re-investment costs<br>- Technical effort (feasibility of construction)<br>• Synergies<br>- Recreational<br>- Commercial benefits<br>- Tourism<br>- Aesthetic focus<br>- Environmental concerns | CBA<br>MCA | Scoring (1-10) | CBA for coastal protection in general<br>MCA for different variations of the general coastal protection solution identified |
| Copenhagen - Cloudbursts | Costs<br>Benefits:<br>• Avoided flood damages | CBA | | |

| Case Study | Evaluation criteria | Method(s) | Weighting approach (only for MCA) | Remarks |
|---|---|---|---|---|
| Kalajoki river basin - Flood risk | Impact on floods:<br>• 1/50-years Flood risk site<br>• 1/100-years Flood risk site<br>• 1/250-years Flood risk site<br>• Elsewhere in the river basin<br>Ecological impact:<br>• Water quality<br>• Biodiversity<br>• Fish<br>Socio-economic impact<br>• Agriculture<br>• Hydropower<br>• Fishing and recreation<br>• Landscape<br>Feasibility<br>• Technical<br>• Financial<br>• Juridical<br>Risks/Uncertainties<br>• Acceptability<br>• Benefits<br>• Negative impacts<br>Costs | MCA | No weighting | |

| Case Study | Evaluation criteria | Method(s) | Weighting approach (only for MCA) | Remarks |
|---|---|---|---|---|
| Kalajoki river basin - Water quality | Costs<br>• Implementation costs of measures<br>Benefits<br>• Reduction in P | CEA | | |
| Holstebro | Costs:<br>• Compensations for farmers for flood retention on their land<br>• Construction costs of dam<br>Benefits:<br>• Annual average flood damage avoided in the event of a 1/1000-year event | CEA<br>CBA | | Innovative approach for estimation farmers WTA by choice experiments |
| Kalundborg | Costs:<br>• Construction costs<br>Benefits:<br>• Avoided flood damage | Comparison of costs and benefits | | |
| Venice | Costs:<br>• Costs of private protection measures<br>Benefits:<br>• Avoided flood damage (=maintenance costs; only direct, tangible damage) | CBA | | |

| Case Study | Evaluation criteria | Method(s) | Weighting approach (only for MCA) | Remarks |
| --- | --- | --- | --- | --- |
| Alentejo | Costs:<br>• Construction costs<br>• Legal fines related with licensing<br>• Water uses and consumption fees<br>• Study costs<br>• (No maintenance costs identified)<br>Benefits:<br>• Land value increase<br>• Income increase due to visitors and events<br>• Ecosystems services, namely Carbon storage | CBA<br>PBCA (prior) | | In this case study the adaptation measured considered also performs a number of socio-environmental services which were mentioned and valued in the PBCA but which could not be translated into monetary values so they are mentioned but excluded from the final CBA NPV calculations. |
| South Aveiro Coast | Costs:<br>• Construction<br>• Implementation<br>• Legal<br>• Expropriation of land<br>Benefits:<br>• Avoided damages (both in real estate and economic activity)<br>• Beach use | CBA<br>MCA | Equal weighting | |

| Case Study | Evaluation criteria | Method(s) | Weighting approach (only for MCA) | Remarks |
|---|---|---|---|---|
| Cascais | Complexity of implementation:<br>• Institutional<br>• Social<br>• Technical<br>Relevance for Cascais:<br>• Urgency<br>• Importance<br>• No-regrets<br>Costs:<br>• Construction<br>• Implementation<br>• Maintenance<br>• Legal | PBCA<br>PMCA | Equal weighting (PMCA) | Validating analyses showed that the criterion set 'Relevance', which included single criteria Importance, Urgency and No-regrets, was highly important for workshop participants to choose the most adequate measures.<br>Information on the (potential) impacts of the measures to be compared was rather mixed. Expert judgements were ambiguous and no validation based on an ex-post analysis was possible as none of the measures has been implemented, yet. |
| Tagus Water District - Madrid | Heat Health Warning System<br>Costs:<br>• Fixed costs (annual)<br>• Variable costs (function of the number of days of alert) which are mainly personnel costs (daily)<br>Benefits:<br>• Avoided mortality (in terms of number of deaths and life years lost) attributable to heat wave, distinction between premature and displaced mortality | CBA<br>Fuzzy Cognitive Mapping (FCM) | Fuzzy Cognitive Mapping<br>• Stakeholders have been asked to evaluate the feasibility of five adaptation strategies proposed by the researchers or their preferences on them. They were asked to say if a specific measure was positive or negative, and had the possibility to express objections (yes/no/yes but). | |

| Case Study | Evaluation criteria | Method(s) | Weighting approach (only for MCA) | Remarks |
|---|---|---|---|---|
| Tagus Water District - Madrid | Green roof<br>Costs:<br>• Implementation costs<br>• Renewing costs<br>• Maintenance costs<br>Benefits:<br>• Energy saving due to a reduced necessity of indoor cooling and due to urban heat island reduction<br>• Reduced necessity of water retention services<br>• Reduced carbon footprint (carbon emission reduction from reduced necessity of energy + carbon sequestration)<br>• Reduce maintenance due to extend life span<br>• Avoided mortality attributable to heat due to the urban het island reduction obtained from green roof | | | |
| Doñana | Costs:<br>• Implementation costs<br>• Market value of land<br>• Loss of economic activity<br>• Conflict with other users of the water district<br>• Environmental looses<br>Benefits:<br>• Environmental benefits<br>• Socio-economic benefits | MCA<br>CBA | | |

| Case Study | Evaluation criteria | Method(s) | Weighting approach (only for MCA) | Remarks |
|---|---|---|---|---|
| Rotterdam – Fluvial flooding | CBA<br>Costs:<br>• Investment costs<br>• Maintenance costs<br>Benefits:<br>• Avoided damages:<br>• Casualties<br>• People affected<br>• Property damages (residential properties including vehicles, businesses)<br>• Infrastructure<br>• Agriculture<br>• Utility companies<br>• Loss of added value due to (temporary) closure of businesses<br>• Indirect damages<br><br>MCA:<br>• Costs (see above)<br>• Avoided damage (see above)<br>• Effects on ecology<br>• Effects on shipping | CBA<br>Adaptation pathway approach<br>MCA | | New way of developing Adaptation pathways by identifying the most efficient pathway |
| Cornwall | Cases of Skin Cancer, Value of skin cancer treatment and welfare effects,<br>Costs from National Institute for Clinical Excellence | CBA | | |

| Case Study | Evaluation criteria | Method(s) | Weighting approach (only for MCA) | Remarks |
|---|---|---|---|---|
| Leeds - Sustainable drainage | Costs:<br>• Capital costs<br>• Maintenance costs (low, medium, high)<br>Benefits:<br>• Water quality improvement<br>• Air quality improvement<br>• Energy savings<br>• Water savings<br>• Consumptive and non-consumptive recreation<br>• Ecology/biodiversity<br>• Aesthetics<br>• Surface and groundwater supply<br>• Carbon sequestration<br>• Climate cooling (health)<br>• Avoided damages | CBA | | Sustainable drainage measures for retrofit are considered. |

| Case Study | Evaluation criteria | Method(s) | Weighting approach (only for MCA) | Remarks |
|---|---|---|---|---|
| Leeds – Ecosystem-based adaptation | Costs:<br>• Planting (+ tree shelters + gates + fencing)<br>• Maintenance (including weeding, scrub clearing, Rhododendron control, re-stocking health issue, labour, thinning, re-spacing)<br>Benefits (Woodland plan elaboration):<br>• Erosion reduction<br>• Runoff reduction<br>• Air quality improvement<br>• Recreation<br>• Aesthetics<br>• Carbon sequestration<br>• Biodiversity<br>• Timber (from thinning)<br>• Avoided damages<br>• Increased land value | CBA | | Unproductive broadleaf woodland planting is considered as an ecosystem-based approach.<br>Previous preliminary studies by the government have mentioned the low effectiveness of upstream water storage for reducing flood risk.<br>Recent research and government publications promote the planting of woodland for flood risk reduction in England. |
| Leeds - Infrastructure | Costs:<br>• Appraisal and design<br>• Construction<br>• Risk<br>• Compensation<br>• Maintenance<br>• Estates<br>• Disruptions to rail and traffic<br>Benefits:<br>• Avoided damages to properties and vehicles | CBA | | |

| Case Study | Evaluation criteria | Method(s) | Weighting approach (only for MCA) | Remarks |
|---|---|---|---|---|
| South Devon Coast - Railway | Costs:<br>• Maintenance and repair costs of the sea wall and the railway infrastructure,<br>• Building of new infrastructure,<br>• Upgrading of existing infrastructure<br>Direct benefits:<br>• Avoided damages to the sea wall and rail infrastructure<br>• Avoided maintenance to the sea wall and rail infrastructure<br>• Avoided statutory compensation to train operators and passengers for travel interruptions<br>Indirect benefits:<br>• Avoided wider economic disruption to the region<br>• Avoided costs of interruptions to freight transport<br>• Avoided costs of interruption to business, commuters and leisure passengers | CBA | | |
| South Devon Coast - Fluvial flooding | Costs:<br>• Capital costs of flood prevention measures (sluice gate and domestic property floodgates)<br>Benefits:<br>• Avoided costs associated with flood damage to properties | CBA | | |
| Mental Health UK | Benefits:<br>• Reduced prescriptions. | CBA | | |

## 2.4 Step 4: Data used, methods used to generate necessary data

**Climate data**

- The single most used climate data set are the CORDEX simulations with the SMHI regional model RCA4-v1 and the boundary conditions from the global climate model CNRM-CM5 for the AR5-IPCC emission scenarios RCP4.5 and RCP8.5.
- This particular data set has been selected as, at the time, it was only model with the appropriate domain (entire European continent) and with a spatial resolution which was adequate for a substantial number of cases, i.e. about 14 km x 14 km. Data has been provided for selected case studies by BASE partner CMCC.
- Still, some case studies needed information on particular climate parameters which could not been retrieved from the data set provided and/or data with a higher spatial resolution. For some cases implausible deviations from historic data and / or projections so far available raised some doubts regarding the validity of the data for some regions provided.[5]
- Some cases (Jena, Prague) decided to use climate data based on an ensemble of global climate models rather than using single model data to better take into consideration inherent uncertainties. These case studies use climate projection data from the Coupled Model Intercomparison Project - Phase 5 (CMIP5) provided by the KNMI Climate Explorer.[6] The Leeds case study opted for the central estimate of the UKCP09 climate projections with a grid resolution of 25 km.

**Socio-economic scenarios**

- Few case studies make use of socio-economic scenarios. The Spanish case studies as well as the Leeds case study apply the SSPs 2 and 5 and the Rotterdam case study use corresponding “steam” and “rest” scenarios.
- In the Green roof case study different scenarios for land use change taken from the ALARM project are used.
- The Kalajoki river basin water quality case study applies four agricultural adaptation scenarios (baseline, successful adaptation, moderate adaptation, little adaptation) and the economic agricultural sector model DREMFIA is used for modelling of the scenarios (Lehtonen 2013).

**Cost data**

The detailed sources of cost and benefit data are often highly case-specific (see Table 2-7 and the descriptions of the case studies in Annex 1 for details regarding specific data sources). In the following the main types of sources are summarised:

- For data on the specific investment costs for certain adaptation measures one of the most important source is data or official plans from the administration, either on the local, regional or national level (e.g. Green roof, Kalundborg, Copenhagen, Leeds, South Devon, Jena, Aveiro Coast).
- Many case studies also use scientific literature to derive cost data (e.g. Madrid, Jena, Leeds) or directly ask expert or scientific institutes (e.g. Madrid, Venice).

[5] For example for the Jena case study data for some parameters, e.g. precipitation related data and global radiation, differed substantially from ECHAM simulations. In general the calibration of ECHAM is considered to be particularly accurate in the re-analysis of measured data for Germany.
[6] Multi-model mean of historical climate data and projections for RCP 4.5, RCP 8.5 of 37 GCMs.

- Private planning or engineering consultancies, construction companies and public services companies are also mentioned as a source to collect cost data, e.g. for green roofs, fountains, pavements, maintenance of water elements, tree care etc. (Jena, Madrid).
- In the Holstebro case study choice experiments are carried out to derive farmers' willingness to accept flood retention on their land.
- In the Rotterdam case study dike reinforcement costs are based on model results (model KOSWAT, Grave & Baarse 2011)

**Benefit data**

- Model results are more frequently used for the estimation of the benefits of adaptation:
- Many case studies apply different flood damage evaluation models to estimate the avoided flood damage: In Prague a Model by Genovese 2006, including GIS data and official damage figures from 2002, the Planning KIT DPRD in Rotterdam (see section 1.4.3), in Copenhagen a model based on flood hazard maps, building cadastral maps and depth damage functions, in the Kalajoki flood risk study model results based on Silander & Parjanne (2013), in Venice a damage model based building cadastral maps, flood data from the municipality (DEM) and depth damage functions derived from expert judgement. Also literature shows that already many flood damage evaluation models exist (for overviews see e.g. Meyer & Messner 2005, Merz et al. 2010, Bubeck & Kreibich 2011, Green et al. 2011, Meyer et al. 2013). All of them require more or less the same input data: flood hazard information, land use data, information on assets at risk, and depth-damage functions. Only the last component is at least to a limited degree transferable to other regions.
- For the estimation of urban heat stress the tool URBAHT (see section 1.4.2) is used at least in two case studies (Jena, Prague), while an innovative CBA approach is applied in the Madrid case study.
- The InVEST model (section 1.4.1) is used in two case studies (Green roof, Alentejo) for the assessment of ecosystem services.
- The WAPA model is used in the Doñana case study (see section 1.4.7).
- In the Kalajoki water quality case study a coupling of different models is used to estimate the cost-effectiveness of agro-environmental measures for P-reduction: The KUTOVA model for CEA calculations, using input data from the VEMALA model on nutrient loads and scenarios for the agricultural sector based on the DREMFIA model (see sections 1.4.4, 1.4.5 and 1.4.6).
- In addition to such model outputs similar types of data sources are used for the estimation of cost figures:
    - Data from official guidelines, statistics, administration (Jena, Kalajoki, Leeds, South Devon, Aveiro Coast),
    - Official plans, maps and land use data (Jena, Prague, Leeds, South Devon, Aveiro Coast, Alentejo, Cascais),
    - Data from scientific literature (Green roof, Jena, Leeds, South Devon, Cascais, Cornwall),
    - Estimations of benefits based on expert consultations in different sector, such as ecology, hydropower, urban planning and flood risk management (Jena, Kalajoki, Rotterdam, Aveiro Coast),
    - Data from insurance companies (Kalajoki, Cascais).
- Furthermore, stakeholder workshops have been carried out to score benefits of different measures (Copenhagen, Kalajoki) as well as a household survey (Kalajoki).

**Use of decision support tools**

- All MCAs, which aim to produce rankings of the alternatives assessed (Jena, Copenhagen, Cascais, Rotterdam, Prague) use PRIMATE (for details see section 1.4.8).

**Table 2-7: Overview step 4: Data collection of BASE case studies**

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| Timmendorfer Strand | Avoided flood damages:<br>• Damage potential analysis<br>Impact of the improvement of the beach promenade:<br>• Regional and local statistical data from the community and neighbouring communities<br>Spendings per day:<br>• Reports published for the community Timmendorfer Strand, for the region Schleswig-Holstein and Germany<br>Change of turnover of restaurant owners (qualitative):<br>• Interviews with owners or staff members<br>Change of property values:<br>• Approximate values for land prices estimated by evaluators (Bodenrichtwerte)<br>Investment costs:<br>• Data from the local community and mainly from the engineering company, which was responsible for the project<br>Maintenance costs<br>• Data from the literature | Data collection based on Reese (2003) | 2011-2100 | • 0%<br>• 1%<br>• 1.5% nationally recommended<br>• 5% |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| Green Roof | Basic socio-economic dynamics:<br>- European ALARM scenarios<br>Land use and land cover change:<br>- European ALARM scenarios & locally-specific trends defined by stakeholders<br>Bundles of land use-based adaptation measures:<br>- Participatory development by stakeholders for each scenario<br>Climate data (levels of precipitation, evapotranspiration):<br>- CORDEX simulations conducted with the SMHI regional model RCA4-v1 using boundary conditions from the global climate model CNRM-CM5<br>- RCP4.5, RCP8.5<br>Costs related to ecosystem services:<br>Artificial water purification by<br>- Sediment retention - Data sources:<br>- Ecosystem-service modelling with InVEST tools<br>- Economic value based on costs of nitrogen removal from water run-off, calculated in a Central European study by Rybanič et al. (1999)<br>- Economic value based on sediment dredging costs, derived from the database of public procurements administered by the Ministry of Regional Development of the Czech Republic<br>- Nitrogen retention - Data sources:<br>- Ecosystem-service modelling with InVEST tools<br>- Economic value based on costs of nitrogen removal from water run-off, calculated in a Central European study by Rybanič et al. (1999)<br>Costs of the implementation of ecosystem-based adaptation measures<br>• Inland marshes and peat bogs restoration<br>• Forest management, operation costs<br>• Maintenance of touristic paths<br>Data sources: Annual reports of the Administration of the NP and PLA of Šumava | | 2006-2050 | No national guidelines for climate change adaptation are available.<br><br>5% (as recommended for public investment projects by European Commission)<br><br>For sensitivity analysis:<br>• 1% |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| | Benefits related to ecosystem services:<br>• Hydropower production<br>• Data sources: Ecosystem-service modelling with InVEST tools, defined as the amount of hydropower generated owing to a water yield provided by adjacent ecosystems.<br>Economic value based on the average subsidy for hydropower production specified by the Energy Regulatory Office of the Czech Republic.<br>• Carbon sequestration<br>• Data sources: Ecosystem-service modelling with InVEST tools. Economic value based on social value of carbon, calculated for the Czech Republic in a study by Hönigová et al. (2012)<br>Benefits of the implementation of ecosystem-based adaptation measures<br>• Timber sales<br>• Sales of services related to hunting<br>• For detailed figures see Table 1: Economic parameters used in the cost-benefit analysis<br>Data sources: Annual reports of the Administration of the NP and PLA of Šumava | | | |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| Jena - Winzerberge | Investment costs:<br>• Private planning office, construction company<br>Maintenance costs:<br>• Municipal service company, City of Jena<br>Heat stress potential:<br>• Modelling with URBAHT<br>- Structural parameters: Data source: Existing drafts, satellite images<br>- Climate parameters: Measurement data: German National Meteorological Service (DWD), Projection data: CMIP5 (RCP 4.5, 8.5), KNMI Climate Explorer<br>Number of parking lots<br>• Existing drafts<br>Amenity value, Architectural quality (5-point Likert scale):<br>• Expert judgement by local planner | | 2015-2050<br>2071-2100 | 3% |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| Jena - Inselplatz | MCA<br>Investment costs:<br>• Department of Urban Development & City Planning, construction company<br>Maintenance costs:<br>• Municipal service company, City of Jena<br>Heat stress potential:<br>• Modelling with URBAHT<br>- Structural parameters: Existing drafts, satellite images<br>- Climate parameters: Measurement data: German National Meteorological Service (DWD), Projection data: CMIP5 (RCP 4.5, 8.5), KNMI Climate Explorer<br>Amenity value, Architectural quality (5-point Likert scale):<br>• Data source: Expert judgement by local planners<br><br>CBA<br>(Re-)Investment, maintenance costs:<br>• Ansel et al. (2011)<br>Benefits:<br>• Stormwater fee savings<br>- JenaWasser (2013)<br>• Energy cost savings<br>- Mann (2005) | | MCA<br>• 2021-2050<br>• 2021-2100<br><br>CBA<br>• 40 years | 1.5%<br><br>For sensitivity analysis:<br>• 3%<br>• 5% |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| | Stormwater management infrastructure savings<br>• City of Portland (2008), Ansel et al (2011)<br>Habitat creation<br>• City of Portland (2008), Costs of creation and maintenance of ecological compensation areas provided by Department of City Planning, City of Jena<br>Carbon Sequestration<br>• Leigh et al. (2014) | | | |
| Jena - Zwätzen | MCA<br>Investment costs:<br>• Department of Urban Development & City Planning, construction company<br>Maintenance costs:<br>• Municipal service company, City of Jena<br>Heat stress potential:<br>• Modelling with URBAHT<br>- Structural parameters: Existing drafts, satellite images<br>- Climate parameters: Measurement data: German National Meteorological Service (DWD), Projection data CMIP5 (RCP 4.5, 8.5), KNMI Climate Explorer<br>Amenity value, Architectural quality, Marketing potential (5-point Likert scale):<br>• Expert judgement by local planner | | 2021-2050<br>2021-2100 | 1.5%<br><br>For sensitivity analysis:<br>• 3%<br>• 5% |
| Prague - Heat stress | Heat stress potential:<br>• Modelling with URBAHT<br>- Structural parameters: Land use classification based on spatial plan of Prague<br>- Climate parameters: Projection data CMIP5 (RCP 4.5, 8.5), KNMI Climate Explorer | | 2014-2100 | |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| Prague - Flood risk | Costs:<br>• Prague city council<br>Benefits:<br>• Based on flood damage estimations<br>• For residential area based on an approach by Genovese (2006)<br>• For other areas/sectors based on 2002 damage figures (adjusted for 2013 prices and furthermore adjusted to different discharge levels in a GIS) | | 2013-2080 | 3%<br><br>For sensitivity analysis:<br>• 1%<br>• 5% |
| Copenhagen - Coastal protection | CBA<br>Costs:<br>• Danish Building and Dwelling Registry (BBR)<br>Benefits:<br>• Flood damages are estimated for different flood events<br>• Six levels of sea water rise assumed (137cm, 158 cm, 200cm, 226cm, 255cm, 285cm)<br>• Damages, especially for living rooms and basements, assessed for each level<br>• BBR register (main categories chosen covering approx. 95% of the flooding) used for assessment<br>MCA:<br>Criteria scores:<br>• Stakeholder judgements collected through workshop | | 2010-2110 | 3%<br><br>For sensitivity analysis:<br>• 1%<br>• 6% |
| Copenhagen - Cloudbursts | Costs:<br>Data source: Danish Building and Dwelling Registry (BBR)<br>Benefits:<br>Flood damage is estimated based on micro-scale damage estimation model | | 2010-2110 | 3%<br><br>For sensitivity analysis:<br>• 1%<br>• 6% |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| Kalajoki river basin - Flood risk | Flood risk estimations:<br>• Study from Silander & Parjanne (2013)<br>• Other statistics - government compensations, insurance companies<br>Annual average willingness to pay for flood protection:<br>• Household survey<br>Impacts on floods:<br>• Experts or consultants responsible for flood risk management planning<br>• Potential data sources: literature, experiences from realised projects<br>Ecological impacts:<br>• Experts responsible for river basin planning, fisheries management and management of Natura 2000 sites<br>• Literature, experiences from realised projects<br>Socio-economic impacts:<br>• Experts responsible for flood risk management planning, city planners, hydropower companies, stakeholders, experiences from realized projects<br>Feasibility:<br>• Experts responsible for flood risk management planning, experts on environmental law, former projects<br>Risks and costs:<br>• Experts responsible for flood risk management planning | Silander & Parjanne (2013) developed a flood damage and risk estimation approach, which is applied in all River Basins in Finland. | Recommended: 50 years<br>For long lasting measures: 100 years | Based on National recommendations for FRM planning, EU guidelines (Parjanne 2014): 3.5%<br>Sensitivity analysis recommended: 5%<br>For very expensive measures with a long lifespan, a discount rate declining in time is recommended:<br>• 1-50yrs: 3.5%<br>• 50-70yrs: 3%<br>• 75-100yrs: 2.5%<br>For sensitivity analysis:<br>• 1%<br>• 5% |
| Kalajoki river basin - Water quality | Mean climate scenario (SRES A1B) is used and 4 socio-economic scenarios (baseline, successful adaptation, moderate adaptation, little adaptation)<br>CEA based on the model KUTOVA developed by SYKE (Hjerppe & Väisänen 2015)<br>Economic agricultural sector model DREMFIA used for modelling of the economic scenarios for the agricultural sector (Lehtonen, 2013)<br>Nutrient loading model VEMALA used for modelling nutrient load (Huttunen et al. 2015a) | | 2021 - 2060 | |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| Holstebro | Dam construction costs<br>• Consultancy report<br>Compensations<br>• Survey data, stated preference method<br>Willingness to accept estimates<br>• Choice experiment<br>Avoided damage cost:<br>• Consultancy report | In a choice experiment farmers were asked to choose among certain bundles of compensation and contract schemes.<br>Estimate of their WTA/ha/yr. range 250-447 EUR depending on contractual characteristics. | 2015-2090 | 1%<br>5%<br>Declining discount rate:<br>• 4% (0-35 years)<br>• 3% (36-70 years)<br>• 2% (>70 years) |
| Kalundborg | Costs:<br>• Association of Danish Mortgage Banks (Realkreditrådet), Statistics Denmark (Statistikbanken), Danish Ministry of Transport (Tranportministeriet)<br>Benefits:<br>• Flood damages determine with flood damage evaluation model | Flooding due to sea level rise analysed separately.<br>Combined effects of sea water, surface water and changes in ground water level not considered.<br>For BAU scenario operation loss of agricultural land not considered<br>Assessment of physical effects of measures with a simple either-or model, where each solution or adaptation measure is analysed separately. | 2010-2090 | No discounting of damage costs and costs of implementation (=undiscounted fixed or annual values) |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| Venice | Costs:<br>• Expert judgement<br>Flood frequencies<br>• Municipal flood centre<br>Flood damage estimations<br>• Depth-damage functions, derived from expert judgement of relevant repair and maintenance costs<br>Building data base including ground floor units, already applied protection measures | 2 sea level rise scenarios considered | 2001 (year of the building survey) - 2050 | • 1%<br>• 3%<br>• 5% |
| Alentejo | Cost:<br>• Ecosystems services (land use changes): InVEST Model<br>• Socio-Economic: Data supplied by the case study regarding the building costs for the WRL as well as for maintenance costs<br>• Legal fees and fines: Law No. 44/2012; ARH<br>Benefits:<br>• Ecosystems services (land use changes): InVEST Model<br>• Socio-economic: Data supplied by the case study regarding number of visits, trainings and events related with the WRL; Land valuation by Crédito Agrícola, INE | | 2015-2050 | 3%<br><br>For sensitivity analysis:<br>• 1%<br>• 5% |

<table>
<tr><th>Case study</th><th>Data</th><th>Remarks</th><th>Evaluation time frame</th><th>Discount rate</th></tr>
<tr><td>South Aveiro Coast</td><td>Costs:<br>• Construction and maintenance of coastal protection measures<br>- Based on expertise and publications of Universidade de Aveiro researchers: Perreira (2014), Roebeling, Coelho, Reis (2011), Roebeling et al (2012)<br>Benefits:<br>• Avoided damages<br>- Land values, insurance prices and region-specific overall house price index obtained from different sources: Fidelidade (2015), INE (2011), INIR (2011)</td><td></td><td>2010 – 2050</td><td>Fix discount rate:<br>• 3%<br>Declining discount rates:<br>• 3.0% - 1.9%<br><br>For sensitivity analysis (declining discount rates):<br>• 1.0 % - 0.6%<br>• 3.0% - 1.9%<br>• 5% - 3.2%</td></tr>
<tr><td>Cascais</td><td>Costs:<br>• Construction and maintenance of adaptation measures<br>- Based on different sources, including technical reports and scientific literature: Hidroprojecto (2001, 2007, 2009, 2014), FCT/C.M.C. (2012), Schulze, Tröltzsch (2012), Mentens et al (2006), Freda (2008), Domenech, Sauri (2011), Gameiro (2010)<br>Benefits:<br>• Avoided damages<br>- Insurance claims empirical data from APS (2014)</td><td></td><td>2010 - 2050</td><td>PBCA:<br>• -5%<br>• -1%<br>• 0%<br>• 1%<br>• 5%</td></tr>
</table>

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| Tagus Water District - Madrid | Emission scenarios<br>• RCP 8.5, RCP 4.5<br>Socioeconomic Scenarios<br>• SSP 5, SSP2<br>Climate data (levels of precipitation, evapotranspiration)<br>• CORDEX simulations conducted with the SMHI regional model RCA4-v1 using boundary conditions from the global climate model CNRM-CM5 sourced from Euro-Mediterranean Center on Climate Change (CMCC)<br><br>CBA Heat & Health Warning System<br>Costs:<br>• Fixed costs of maintenance<br>• Average variable cost<br>Benefits:<br>• Changes in attributable risks, i.e. daily mortality attributable to heat waves, above critical threshold<br>• Changes in displaced mortality<br>• Changes in premature mortality<br>CBA Green roof<br>Costs:<br>• Installation, maintenance costs sourced from CYPE Ingenieros, Catalonia Institute of Construction Technology Itec, Manufacturer of building products DANASO, TEXSA<br>Benefits:<br>• Avoided water treatment costs<br>• Avoided electricity consumption from Air conditioning<br>• Carbon sequestration: Time series from DEFRA | | 2020-2100 | • 0%<br>• 1%<br>• 2%<br>• 3%<br>• 5% |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| Doñana | Emission scenarios:<br>• RCP 8.5, RCP 4.5<br>Socioeconomic Scenarios:<br>• SSP 5, SSP 2<br>Climate data:<br>• WAPA, Public service organization in charge of the water resources policy, water management and irrigation planning in the Guadalquivir River Basin District and the River Basin Authorities<br>Costs:<br>• Consulting of experts and stakeholders<br>Benefits:<br>• Stakeholders | | 2010-2100 | |
| Rotterdam – Fluvial flooding | CBA<br>Costs:<br>• Planning Kit DPRD<br>Dike reinforcement:<br>• Model KOSWAT (Grave & Baarse, 2011)<br>Benefits:<br>• Damage avoided:<br>  - Planning Kit DPRD<br>• Values for statistical life, people injured and people affected<br>  - Kind (2011)<br>MCA:<br>• Scores determined through consultation of experts | | 2017-2100 (considering residual values of measures until 2150) | 5.5 % |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| Cornwall | Cases of Skin Cancer, Value of skin cancer treatment and welfare effects, Costs from National Institute for Clinical Excellence review | Evaluating benefits and costs of public health campaign on skin cancer | Annual | B/C ratios calculated annually as would be annually renewing measure |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| Leeds - Sustainable drainage | Climate data:<br>• UKCP09 climate projections, three greenhouse gas emission scenarios:<br>- High: SRES A1FI (equivalent to IPCC SRES, RCP 8.5)<br>- Medium (equivalent to SRES A1B)<br>- Low (equivalent to SRES B1, RCP 4.5)<br>Costs:<br>• Cost data sourced from consultancy and NGO documents (CIRIA 2013; Eftec 2010; HR Wallingford 2004; UKWIR Ltd. 2005), government documents (e.g. Environment Agency 2007), local data (e.g. Yorkshire Water 2014), among others<br>Benefits:<br>• Benefit data estimated indirectly from an array of UK government and scientific publications, mainly valuation studies<br>• Cost incurred by Yorkshire Water to treat sewage is used as the benefit of improved water quality<br>• Benefits data based directly or indirectly on the following documents: Environment Agency (2007), Roebuck et al. (2011), Royal Haskonings (2012), Sustrans (2010) and Woodland Trust (2011)<br>Key data sources:<br>• Aire Catchment Flood Management Plan (2010),<br>• CIRIA (2013). CIRIA Research Project RP993: Demonstrating the multiple benefits of SuDS – A business case (Phase 2)<br>• Environment Agency (2007). Retrofit SUDS for Urban Water Quality Enhancement.<br>• Environment Agency (2007). Cost-benefit of SUDS retrofit in urban areas Science Report – SC060024<br>• Forest Research (2010): Benefits of green infrastructure. Report to Defra and CLG. Forest Research, Farnham; Royal Haskoning DHV (2012): Costs and Benefits of Sustainable Drainage Systems | | 2014 - 2114 | Declining long-term discount rate:<br>• 1-30 years: 3.5%,<br>• 31-75 years: 3%<br>• 76-125 years: 2.5%<br><br>For sensitivity analysis:<br>• 1%<br>• 5% |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| Leeds – Ecosystem-based adaptation | Climate data:<br>• UKCP09 climate projections, three greenhouse gas emission scenarios:<br>- High: SRES A1FI (equivalent to IPCC SRES, RCP 8.5)<br>- Medium (equivalent to SRES A1B)<br>- Low (equivalent to SRES B1, RCP 4.5)<br>Costs:<br>• Cost data based on the recent Woodland Capital Grants 2015 of the UK government and Forestry Commission documents<br>Benefits:<br>• Benefit data is based mainly, directly or indirectly, on CJC Consulting (2014), Defra (2011), Eftec (2010), Smith et al. (2012), Valatin and Starling (2010), and Woodland Trust (2015)<br>Key data sources:<br>• Aire Catchment Flood Management Plan (2010), Flood risk assessments for Leeds (2008, 2011), Local Climate Impacts Profile for Leeds (2009), Broadmeadow, Nisbet (2010): 64pp, Defra (2011): 29pp, Miles (2014): 30pp | | 2014 - 2114 | Declining long-term discount rate:<br>• 1-30 years: 3.5%,<br>• 31-75 years: 3%<br>• 76-125 years: 2.5%<br><br>For sensitivity analysis:<br>• 1%<br>• 5% |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| Leeds - Infrastructure | Climate data:<br>• UKCP09 climate projections, three greenhouse gas emission scenarios:<br>- High: SRES A1FI (equivalent to IPCC SRES, RCP 8.5)<br>- Medium (equivalent to SRES A1B)<br>- Low (equivalent to SRES B1, RCP 4.5)<br>Costs/Benefits:<br>• Data on costs and benefits based on existing schemes, including the currently implemented city centre scheme, and the planned Wyke Beck and Wortley Beck schemes for hard infrastructure<br>• Data for other Leeds District areas estimated based on the above sources<br>Data sources:<br>• Aire Catchment Flood Management Plan (2010), Flood risk assessments for Leeds (2008, 2011), Local Climate Impacts Profile for Leeds (2009), Leeds city centre Flood Alleviation Scheme Project Appraisal Reports (2010, 2013), West Garforth Integrated Urban Drainage (2008), Documents towards the development of the Wyke Beck flood alleviation scheme (2008 - 2010) | | 2014 - 2114 | Declining long-term discount rate:<br>• 1-30 years: 3.5%,<br>• 31-75 years: 3%<br>• 76-125 years: 2.5%<br><br>For sensitivity analysis:<br>• 1%<br>• 5% |
| South Devon Coast - Railway | Costs:<br>• Delay costs<br>• Costs of upgrading sea defences<br>• Costs of alternative routes<br>Data sourced from research by Dawson (2012), including much of the baseline (monetary) data regarding the likely impacts and costs of climate change on the Dawlish railway line | | 2015-2080 | 3.5%<br><br>For sensitivity analysis:<br>• 1%<br>• 10% |

| Case study | Data | Remarks | Evaluation time frame | Discount rate |
|---|---|---|---|---|
| South Devon Coast - Fluvial flooding | Costs:<br>• Average ground floor flooding costs<br>- UK Environment Agency<br>• Average costs of flood protection gates<br>- Municipality<br>• Cost of sluice gate<br>- Municipality<br>Benefits:<br>• Avoided costs of flooding<br>- UK Environment agency | | 2015-2080 | 3.5%<br><br>For sensitivity analysis:<br>• 1%<br>• 10% |
| Mental Health UK | Panel data on monthly surgery level prescription data and climate data in England. | | 2010/2012 - 2050 | |

## 2.5 Step 5: Evaluation results

Table 2.8 provides an overview of each case study results. In the following section 3.1 key results for the different risks addressed will be summarised (see also table 3.1 for an overview of cost and benefit figures for certain types of measures and risks addressed).

**Table 2-8: Overview step 5: Evaluation results of the BASE case studies**

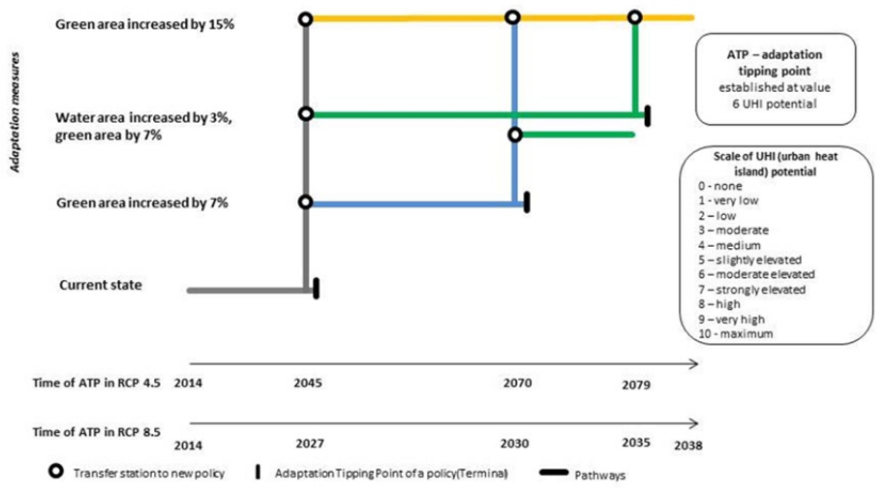
| Case study | Type of results | Results | Comments |
|---|---|---|---|
| Timmendorfer Strand | • Net present costs<br>• Net present benefits<br>• NPV differences to BaU<br>• BCR | The investment-upfront costs are the major type of costs and the main type of benefits is avoided damages by storm surges.<br>Also the additional tourism shows substantial benefits.<br>The Net present value is positive for both scenarios (Minimum-Scenario RCP2.6, Maximum Scenario: RCP4.5 and RCP 6.0) and the Benefit-Cost-Ratio is higher than one.<br>For the discount rate of 1.5%:<br>• The total costs for the minimum scenario are: 30.1 m Euro and for the maximum scenario: 30.3 m Euro. The costs can be split in investment and maintenance costs. The investment costs with 30 m Euro are the same for both scenarios. The maintenance costs are 125,000 Euro for the minimum scenario and 375,000 for the maximum scenario.<br>• The total benefits are 122.3 m Euro for the minimum scenario and 250.1 m Euro for the maximum scenario. The benefits can be divided in the following benefit components: change in land value, effects on tourism and avoided damages. Land values increased for the min-scenario by 5.9 m Euro, for the max-scenario by 8.6 m Euro. The additional tourism accounts for 44.8 m Euro (min-scenario) to 72 m Euro (max-scenario). Avoided damages cover 71.5 m Euro for the min-scenario and 169.6 m Euro for the max-scenario.<br>• The Net present value is 92.1 m Euro for the min-scenario and 219.8 m Euro for the max-scenario. The benefit-cost-ratio is estimated by 4.1 for min-scenario and 8.2 for max-scenario).<br>For the discount rate of 0%:<br>• The Net present value is between 201.0 and 443.4 m Euro (min and max-scenario). The Benefit-cost ratio differs between 7.7 (min-scenario) and 15.5 (max-scenario).<br>For the discount rate of 1%:<br>• The Net present value is estimated with 118.8 m Euro for the min-scenario and 273.9 m Euro for the max-scenario. The Benefit-cost-ratio for the two scenarios varies between 4.9 and 10.0.<br>For the discount rate of 5%:<br>• For a 5 %-discount rate the Net present value is estimated with 13.3 and 62.5 m Euro (min-, max-scenario). The Benefit-cost-ratio is 1.4 for the min-scenario and 3.1 for the max-scenario. | |

| Case study | Type of results | Results | Comments |
|---|---|---|---|
| Green Roof | • Net present costs<br>• Net present benefits<br>• NPV differences to BaU | Cost-benefit analysis for four strategies under RCP4.5 and RCP8.5 (net present value differences compared to BaU, 2006-2050, in EUR):<br>• The Green strategy reaches the highest NPV (2006-2050, 5%) of 63-73 m EUR under RCP4.5 scenario, followed by the Shared Vision (16-22 m EUR as a range resulting from accounting for minimum to maximum unit values of different ecosystem services).<br>• The Red strategy, not incorporating ecosystem-based adaptation measures, had a negative NPV (-28 - -31 m EUR) as a result of a declining provision of ecosystem services. Under RCP8.5 scenario, the resulting NPVs were approximately 15% lower, suggesting a negative impact of the more extreme climate scenario on the provision of ecosystem services.<br>• The NPVs (2006-2050) calculated at 1% discount rate for RCP4.5 scenario were 137-170 m EUR for the Green strategy, 47-60 m EUR for the Shared Vision and -35 - -45 for the Red strategy. For RCP8.5 scenario, the NPVs were approximately 20% lower.<br>The results suggest that the implementation of ecosystem-based adaptation measures brings substantial benefits in terms of the provision of ecosystem services in the case study area and incurs lower management costs as a result of the implementation of non-intervention nature protection zones. | |
| Jena - Winzerberge | • Ranking<br>• MCA scores | • Alternative 8 – Draft 2, use of large-crowned tree species, light-coloured pavement – outperforms all other alternatives This holds with a probability of 96% in the medium term and with a probability of 91% also in the long term perspective. The result is statistically robust.<br>• The overall performance of the four variations of Draft 2 is better than the ones being based on Draft 1. Therefore, Draft 2 can be regarded as the superior basic draft. The most important advantage of Draft 2 is the lower degree of soil sealing. For a detailed description of the basic drafts see section 6.3 in annex 3.<br>• Light-coloured pavements as well as large-crowned trees have a beneficial impact on site-specific micro-climatic conditions. In the short and medium term this effect is similar, but as time elapses the positive effect of large-crowned trees continuously increases whereas the benefits of the light-coloured pavements are immediate but static. | |

| Case study | Type of results | Results | Comments |
|---|---|---|---|
| Jena - Inselplatz | • Ranking<br>• MCA scores | MCA<br>• Alternative 3 (greenest option) ranks first, alternative 2 second and alternative 1 third (smallest amount of green structures) in the medium (2021-2050) as well as in the long-term period (2021-2100).<br>• In the medium (long-term) perspective the respective probabilities are 97% (95%) of alternative 3 ranking first, 88% (82%) of alternative 2 ranking second and 90% (86%) of alternative 1 ranking third. Results are statistically significant.<br>• Light-coloured pavements and large-crowned trees have a beneficial impact on site-specific micro-climatic conditions. The partly higher costs also pay-off with regard to the criteria amenity value and architectural quality.<br>• When comparing the net present costs of a small-crowned and a large-crowned tree over a longer period, e.g. 82 years, regarding tree procurement, planting, replanting and care costs using a 1.5 % discount rate these costs add up to 2,254 EUR for small-crowned tree and 2,121 EUR for large-crowned tree. Furthermore, the latter has a much more beneficial impact on the site-specific micro-climate.<br>• The influence of the artificial water course is more ambiguous as it is quite costly and has – due to its dimension – only a limited impact on the micro-climate. Its overall value largely depends on how it is assessed with regard to its influence on criteria as amenity value and architectural quality.<br>• The use of green roofs has a positive impact on the incurring costs when using the discount rate recommended by German authorities, i.e. 1.5%. | |

| Case study | Type of results | Results | Comments |
|---|---|---|---|
| Jena - Inselplatz Cont. | • NPV | CBA<br>• A comparison of the net present values (40 years, 1.5%, 3% and 5%, only private benefits) of 1 $m^2$ of an extensive green roof compared to 1 $m^2$ of a tar-gravel roof leads to the following results:<br>• Consideration of cost differences and stormwater fee savings of an extensive green roof cover compared to a tar-gravel roof cover savings add up to 0.07 to 0.32 EUR/$m^2$ p.a. (40 years, 1.5%, most / least expensive green roof type).<br>• Consideration of additional (private) benefits, i.e. private stormwater management savings, energy cost savings further improves the results in favour of the green roof cover. Savings then add up to 0.52 to 0.70 EUR/$m^2$ p.a. (40 years, 1.5%, most / least expensive green roof type).<br>• Higher discount rates reduce the overall savings. When applying a 5% discount rate and only considering cost differences and stormwater fee savings additional costs for a green roof cover of 0.18 EUR/$m^2$ p.a. accrue. For details see<br>• Public benefits are rather low compared to private benefits, i.e. the annual value of the habitat created and carbon sequestered are about 0.03 EUR/$m^2$ each (40 years). In absolute terms the habitat creation value is 1.39 EUR/$m^2$, i.e. 4,941 EUR for alternative 1, 8,351 EUR for alternative 2, 11,327 EUR for alternative 3. The value of the carbon sequestered by the green roof covers in absolute terms adds up to 116 EUR p.a. for alternative 1, 197 EUR p.a. for alternative 2, 267 EUR p.a. for alternative 3.<br>• Using the officially recommended discount rate all green roof covers are efficient in a minimum-benefit (cost differences & stormwater fee savings) and a maximum-benefit (cost differences & stormwater fee savings & private stormwater management & energy savings) perspective.<br>• Using a 3% discount rate only the most expensive type of green roof cover is not efficient in a minimum-benefit perspective.<br>• Using a 5% discount rate only the least costly type of green roof cover is efficient in a minimum-benefit perspective. In a maximum-benefit perspective all green roof covers are efficient. | |

| Case study | Type of results | Results | Comments |
| --- | --- | --- | --- |
| Jena - Zwätzen | • Ranking<br>• MCA scores | MCA<br>• Alternative 3 (greenest option) ranks first, alternative 1 (smallest amount of green structures) second and alternative 2 third in the medium as well as in the long-term period. For detailed information on the alternatives see Table 2-3 and section 6.5 in annex 3.<br>• In the medium perspective this result is certain. In the long-term perspective the respective probabilities for this ranking are 98% of alternative 3 ranking first, 98% of alternative 3 ranking second and 100% of alternative 2 ranking third.<br>• Uncertainty in the results is a consequence of the uncertainty in climate input data and comparatively low. Results are statistically significant.<br>• Performance of alternatives varies substantially across the criteria. With regard to the criteria costs (20%) and marketing potential (20%) alternative 1 clearly outperforms alternative 3, which in turn performs much better regarding the criteria architectural quality (30%), amenity value (20%) and heat stress potential (10%). The at first sight seemingly small differences between alternative 2 and 3 turn out to have a major impact on the overall assessment result.<br>• The overall effect of the use of light-coloured paving materials as well as large-crowned trees on the heat stress potential and the amenity value is much more beneficial than additional financial burden caused by these adaptation measures.<br>• Although the greener alternatives perform well with regard to the criteria amenity value and architectural quality, they – against the prevailing assumption – do not always enhance the marketing potential of a property. This points to the negative aspects associated with green infrastructure, as e.g. less incidence of light, higher energy costs in winter, and other disturbance. | |

| Case study | Type of results | Results | Comments |
|---|---|---|---|
| Prague - Heat stress | • Adaptation pathway map | <br>The figure above presents the adaptation pathway map for the three adaptation measures, i.e. (1) increase in green area by 7%, (2) increase in water area by 3% and greenery by 7%, (3) greenery increased by 15%, to reduce the urban heat island (UHI) effect for the case study area in Prague.<br>The results show that under RCP 4.5, adaptation measures have substantial impact on UHI reduction. However, UHI potential is significantly increasing under RCP 8.5 and adaptation measures are sufficient only to year 2033.<br>Therefore, there is a need for additional adaption options to maintain heat stress potential below an URBAHT score 6 of adaptation tipping point (moderately elevated UHI potential). | |
| Prague - Flood risk | • NPV | The annual average damage avoided by the Flood control system is estimated to be 37 m EUR.<br>We assume that an event (which initiates installation costs) occurs approximately every 20 years. The results are following:<br>• For 3% discount rate: NPV = 918 m EUR<br>• For 1% discount rate: NPV = 1,872 m EUR<br>• For 5% discount rate: NPV = 599 m EUR<br>The current FCS is, even despite its high cost, highly efficient. | |

| Case study | Type of results | Results | Comments |
|---|---|---|---|
| Copenhagen - Coastal protection | CBA<br>• NPV of coastal protection scheme<br>MCA<br>• MCA scores<br>• Ranking | CBA:<br>• Net present benefits: 2.67 m EUR<br>• Net present costs: 0.54 m EUR<br>• Net present value: 3.31 m EUR<br>MCA:<br>• Uncertainties in scores, but the alternative proposed by working group 1 was ranked best | CBA<br>• Sensitivity analysis is carried out for different discount rates, different unit prices (input for flood damage evaluation) and different cost estimates<br>MCA<br>• Use of a particular weighting set for each stakeholder group<br>• Use of triangular distributions of (uncertain) input data |
| Copenhagen - Cloudbursts | • NPV | Alternative 4, i.e. Only backflow valve in all basements plus surface adaptation, is most efficient:<br>• Net present value Alternative 1: - 37 m EUR<br>• Net present value Alternative 2: 264 m EUR<br>• Net present value Alternative 3: 53 m EUR<br>• Net present value Alternative 4: 1,104 m EUR<br>• Net present value Alternative 5: 91 m EUR | |

| Case study | Type of results | Results | Comments |
|---|---|---|---|
| Kalajoki river basin - Flood risk | CBA:<br>• Payback time<br>• Internal rate of return (IRR)<br>MCA<br>• Decision matrix, no weighting, but discussion of results on stakeholder workshops<br>Prioritisation based on<br>a) Stakeholder workshop<br>b) Household survey<br>c) Final prioritisation in the flood management group | Embankments most efficient (payback time 23.7 years)<br>Prioritisation based on MCA, stakeholder workshop, household survey and finally flood management group (after public hearing of the plans):<br>Primary measures:<br>• Flood risk mitigation and preparedness (current measures)<br>• Operational flood risk management (current measures)<br>• Maintenance of existing flood embankments<br>• Increasing water retention capacity of the river basin<br>• Recovery<br>Secondary measures<br>• New permanent flood protection structures<br>Complementary measures<br>• Flood documentation with help of citizens<br>• Using agricultural land as floodplains | Embankments most efficient when only the flood risk management is considered. |

| Case study | Type of results | Results | Comments |
|---|---|---|---|
| Kalajoki river basin - Water quality | Cost effectiveness of different agro-environmental measures (E/kg P) for different scenarios | All measures will become more cost effective in future climate due to higher input load.<br>In the Climate change scenario the cost-effectiveness for all measures would be better than in the present state, in the period of 2021-2030 the price tag for reduced phosphorus would be 6 % smaller and in 2051-2060 22 % smaller.<br>• This is a consequence of the larger share of total loading caused by the agriculture for example a wetland reducing 34% of the incoming loading would retain more phosphorus (in kilograms) if the incoming loading is larger.<br>For Little and Moderate adaptation scenarios so-called field measures (buffer zones, winter time vegetation and perennial grass) are not as cost-effective as they are now.<br>• The cost-effectiveness of wetlands, controlled drainage and optimal fertilization is better in these scenarios than in present.<br>In the successful adaptation scenario all the measures would be more cost-effective in future than they are now.<br>Evaluation of the effectiveness of the agro-environmental measures in the current river basin management plans and for cost-effective combinations of measures in all scenarios in River Kalajoki catchment.<br>Planned mitigation measures and the cost-effective combination of measures would struggle to achieve the current loading level, not to mention the target level of good ecological status.<br>From the agricultural change scenarios the successful adaptation would best compensate for the increase of total phosphorous caused by climate change. Even though, the current loading level could not be achieved in 2051-2060. | Uncertainties related to the cost-effectiveness calculations are analysed by the KUTOVA-tool with Monte Carlo simulation and can be presented as range, standard deviation or frequency distribution of the cost-effectiveness in simulations (Hjerppe, Väisänen 2015). |

<table>
<tr><th>Case study</th><th>Type of results</th><th>Results</th><th>Comments</th></tr>
<tr>
<td>Holstebro</td>
<td><ul><li>Compensation cost estimates for two different retention levels</li><li>Costs for building the necessary dam withstanding a 1/100-year event</li><li>Avoided damage costs of a 1/1000-year event</li></ul></td>
<td>
Assuming that the town of Holstebro would decide to construct a dam that could resist a 100-year event, costs of the farmer as water manager measure would be at least 12,340 EUR per m $m^3$ retained (price depends on the contractual content and dam solution). These costs only include the costs of paying farmers to retain water on their fields, not costs of the dam included.
Cost-effectiveness results:
<ul>
<li>Option 1: 156 ha farm land required, retention capacity of 2.9 m $m^3$<br>13,455 – 24,065 EUR/m $m^3$ retained</li>
<li>Option 2: 148 ha farm land required, retention capacity of 3 m $m^3$<br>12,340 – 22,070 EUR/m $m^3$ retained</li>
</ul>
The table below clearly indicates that assuming current levels of avoided costs and in the event of a 1-in-1000 year flooding under a protection level for a 1-in-100 year event, adaptation costs outweigh benefits, independently of farmer level payments. If, however, we take future economic growth and hence the increase in values of infrastructures and property into account, based on the development of GDP in Denmark under the SSP2 and SSP5 scenarios, the balance moves in favour of adaptation (i.e. avoided damages increase)
Table: Cost Benefit Results of Different SSP Scenarios and Discount rates (Net Present Values in m Euro)
<table>
<tr><th rowspan="2">Scenario</th><th colspan="3">Discount rate</th></tr>
<tr><th>Decreasing*</th><th>1%</th><th>5%</th></tr>
<tr><td colspan="4">Assuming current level of benefits</td></tr>
<tr><td>Highest compensation level</td><td>-2.83 m EUR</td><td>-2.6 m EUR</td><td>-2.86 m EUR</td></tr>
<tr><td>Lowest compensation level</td><td>-2.08 m EUR</td><td>-1.06 m EUR</td><td>-2.26 m EUR</td></tr>
<tr><td colspan="4">Assuming levels of benefit following economic development under SSP 2</td></tr>
<tr><td>Highest compensation level</td><td>-1.54 m EUR</td><td>1.36 m EUR</td><td>-2.02 m EUR</td></tr>
<tr><td>Lowest compensation level</td><td>-0.79 m EUR</td><td>2.95 m EUR</td><td>-1.43 m EUR</td></tr>
<tr><td colspan="4">Assuming levels of benefit following economic development under SSP 5</td></tr>
<tr><td>Highest compensation level</td><td>-0.71 m EUR</td><td>3.97 m EUR</td><td>-1.48 m EUR</td></tr>
<tr><td>Lowest compensation level</td><td>0.04 m EUR</td><td>5.56 m EUR</td><td>-0.89 m EUR</td></tr>
</table>
*4% (0-35 years); 3% (36-70 years); 2% (>70 years)
</td>
<td></td>
</tr>
</table>

| Case study | Type of results | Results | Comments |
|---|---|---|---|
| Kalundborg | Risk maps showing the aggregated flood risk<br>Solution 1 & 2<br>• Construction costs and benefits, i.e. avoided damage costs including water abstraction<br>Solution 3 & 4<br>• No detailed cost and benefit figures | Solution 1<br>• Offshore dike with high water level locks:<br>- Costs: 80 m EUR,<br>- Benefits: by 2067 80 m EUR; by 2090 147 m EUR<br>• Offshore dike with locks and pumps<br>- Costs: 0.61 bn EUR<br>- Benefits: by 2067 82 m EUR; by 2090 241 m EUR<br>Solution 2<br>• Coastal dikes<br>- Costs: 17 m EUR<br>• Dikes along Nedre Halleby Stream<br>- Costs: 5.2 m EUR<br>• New outlet for Nedre Halleby Stream north Bjerge Sydstrand<br>- Costs: 0.7 – 1.3 m EUR<br>• Counter-current lock in Nedre Halleby Stream<br>- Costs: 0.4 - 0.7 m EUR<br>• 4 pump stations in connections with coast dikes<br>- Costs: 0.7 - 4 m EUR<br>Total costs: 37 m EUR<br>Total benefits: by 2045 38 m EUR; by 2090: 241 bn EUR | |

| Case study | Type of results | Results | Comments |
|---|---|---|---|
| Venice | • PV of costs<br>• PV of benefits (damage avoided)<br>• PV of residual damages<br>• NPV (PVB – PVC) | For three options costs exceed the (monetary) benefits: present state, full impermeabilization (dry flood proofing), raising floor levels.<br>Only the option “small adaptation measures” is efficient, at least for discount rates of 1 and 3%, not for 5%, and residual damages remain high in this option.<br>But intangible effects (avoided stress etc.) are not included. | |
| Alentejo | • NPV | The NPV of the Water Retention Landscapes of Tamera regarding the aspects considered is negative in 261,551 EUR.<br>The high costs involved in the construction of the lakes are not outweighed by the discounted benefits, which would be a strong argument against the development of the 1,000 Lakes for the Alentejo vision.<br>However, we must acknowledge that slight changes in the discounting of benefits would have a major impact in the NPV – as the sensitive analysis demonstrates. Furthermore, the price of water is expected to increase over the next years and the value of resilient ecosystems will be much valued in such semi-arid regions.<br>We have decided not to include such projections as uncertainty and competing theories for such important factors undermine scientific consensus.<br>Finally, another important variable, which was also excluded from the analysis was increased agriculture production due to lack of reliable data and direct causal link with the WRL. Further research in the future might include this and contribute to a more balanced NVP. | |

| Case study | Type of results | Results | Comments |
| --- | --- | --- | --- |
| South Aveiro Coast | • NPV<br>• BCR | Scenario simulation results show that neither Scenario 1 nor Scenario 2 is expected to provide positive returns to investment. Although these scenarios completely halt land cover losses and reduce flooding risk, investment and maintenance costs are up to almost 70% larger than the expected benefits.<br>Scenario 3 is expected to provide positive returns to investment as it halts land cover losses and eliminates flooding risk, while entailing lowest recurrent investment and maintenance costs.<br>Hence, scenarios involving large artificial beach nourishments and minor hard intervention measures are not attractive from an economic perspective, due to the high recurrent investment costs associated with the beach nourishments; scenarios combining small artificial beach nourishments and major hard intervention measures are attractive from an economic perspective, as they entail lowest recurrent costs while equally providing considerable benefits.<br>Across all scenarios, largest benefits are obtained when artificial beach nourishments take place once every two years.<br>The sensitivity analyses, on discount rates as well as cost and benefit variations, show that these results are consistent. Decreasing costs and discount rates as well as increasing benefits lead to improved performance indicators for all scenarios. A 10% reduction in costs or increase in benefits is, however, not sufficient to provoke positive returns to investment for Scenario 1 and 2, although returns to investment are approaching the minimum required levels for Scenario 2. Cost overruns of 50% would put the viability of Scenario 3 in question. Largest benefits continue to be obtained when artificial beach nourishments take place once every two years. | |
| Cascais | • Cost-effectiveness ratio<br>• Rankings based on MCA, participative prioritizations | On the basis of the cost-effectiveness analysis for a rainstorm extreme event (T = 100) for Ribeira da Vinhas the strong argument in favour of rainwater gardens and green corridors/re-naturing of the Riberia can be made as they provide by far the best $m^3$/EUR ratio.<br>Measures such as Rainwater harvesting and Green roofs are due to the high investments costs less appealing for stakeholders looking for low or no-regret measures. However, their ratio might even increase dramatically from the stand point of the municipality, if it is considered that a great part of the investment can be made by the households themselves yielding private benefits. Subsidizing the adoption of such solutions might prove to be a promising strategy for Cascais Municipality but demand elasticity and sensitivity curves have to be further researched.<br>Finally, taking into account the avoided damages for a 10 year period reported for Cascais (1 m EUR) and for Ribeira das Vinhas (approx. 100,000 EUR), with the actual budget only the Green corridors and a subsidized option for private decentralized rainwater catchment would have a positive cost-benefit difference. The PBCA ratio points to the option Green corridors. | |

| Case study | Type of results | Results | Comments |
|---|---|---|---|
| Tagus Water District - Madrid | • NPC<br>• NPB<br>• BCR | The case study focuses on two measures: (i) an early warning system to reduce the impact of high temperatures on health and (ii) the construction of green roofs as a means to reduce the urban heat island effect.<br>The results of the cost-benefit calculations of both measures show the effectiveness of the HHWS is very high, while there is a great difficulty to calculate the costs and benefits of the implementation of green roofs over all in existing neighbourhoods. The main results can be summarized as follows:<br>• HHWS. As demonstrated for Madrid, a HWWS is a low regret urban adaptation option to climate change, and consequently, highly relevant for decision-making. The HWWS usefulness depends on the correct specification of the critical temperature threshold ($T_{crit}$). Current long-term studies of heat wave impacts assume constant $T_{crit}$, but decadal variations of $T_{crit}$ have been reported in Castilla-La Mancha, Spain. Failure to recognize time-dependence of $T_{crit}$ is likely to render HWWS, and other urban adaptation measures, inefficient, and potentially cost-ineffective.<br>• Estimating the benefits of Green roof in physical, non-monetary terms is a very challenging exercise given the little (but increasing) knowledge on green roofs at meso-scales. The most uncertain one is the urban heat island (UHI) effect reduction. If UHI is well documented for Madrid at spatial scale, the contribution of green roof in reducing UHI is mostly unknown in Madrid, in a single estimation isolated of other adaptation measures like air conditioning reduction. The benefit-cost ratios vary from almost 0 to 3.5 according to the combination of low, medium and high cost and benefits. The decision relative to the profitability of green roof is very uncertain.<br>The case study has divided the effects of the green roofs in:<br>• Water retention<br>• Maintenance reduction. Results for Green roofs coverage of 20% below<br>• Energy savings/avoided $CO_2$ emissions. Results for Green roofs coverage of 20% below.<br>• Avoided mortality<br>The value of avoided mortality is larger in the low mitigation scenario (scenario SSP5/RCP8.5) than in higher mitigation scenario (SSP2/RCP4.5). Although this effect is diluted with the discount rate effect: future avoided mortality is less valued as the discount rate increases. | |

| Case study | Type of results | Results | Comments |
|---|---|---|---|
| Doñana | MCA decision matrix | The results of the consulting process can be grouped as follows:<br>Technological adaptation measures:<br>• Technological measures to increase water efficiency at the field level were most likely to be accepted by farmer associations and environmentalists, e.g. water recirculation and reutilization within the paddy rice or increased technical efficiency of the irrigation systems. Other technological options, which have already proven benefits to the rice production and are widely implemented in the area, e.g. laser levelling and integrated production, were also fully supported by the administration.<br>Organizational adaptation measures:<br>• Organizational measures related to water management were positively perceived by the farmer associations and environmentalists. Their responses reflected that there is a lack of local monitoring and information on water availability and use. In the perceptions of the two groups, farmer associations and environmentalists, there is also a need of anticipating management options to local water shortages. Once problems have arisen, reactive management efforts can be more costly than anticipating management to reduce risk by actions to enhance the resilience of the river basin. Proactive management efforts may include among others: management plans to the risk of water scarcity at the farm level, on-farm reservoirs, improvements in water use efficiency. The high number of “no opinion” answers obtained within the category of “administration support” to technological or organizational options is striking. It suggests to some extent a limited commitment to measures addressed at farm or local scale on this topic. Most of questions concerning to governance options were perceived to be supported by the administration, since it directly fall in their scope of action.<br>Governance adaptation measures:<br>• Governance measures included options addressed to improve the coordination between institutions. The critical importance of institutional good governance has been previously established as a requirement for the regional adaptation capacity by preceding research. Increase scientific research, farmer training and technical advice were positively perceived by all groups. Finally, a lack of confidence in the truth or efficacy of governance measures addressed to climate change strategies and environmental awareness is often referred in the farmer associations’ responses. These results prove that climate change and environment can be concepts which are not be easily grasped, and tends to be something that is less tangible to farmers. Experts also pointed out the need of encouraging the farmers’ long-term views by climate change advisement and capacity building.<br>Results show that it is difficult to find adaptation options, which are in line with the preferences of all 3 groups. | |

<table>
<tr><th>Case study</th><th>Type of results</th><th>Results</th><th>Comments</th></tr>
<tr>
<td>Rotterdam – Fluvial flooding</td>
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CBA

- NPV for the different options in the different time periods
- Based on that: Pathways of the most efficient options

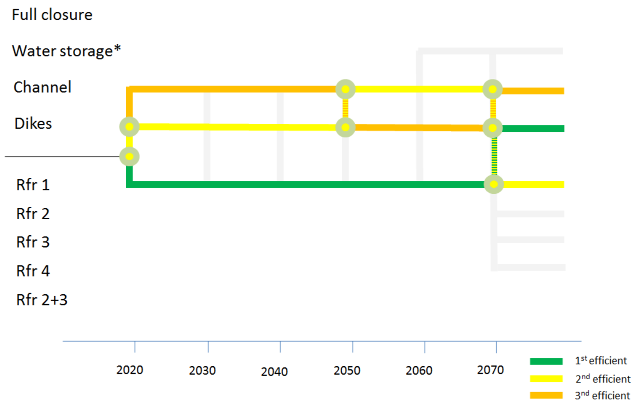
MCA

- MCA scores
- Ranking

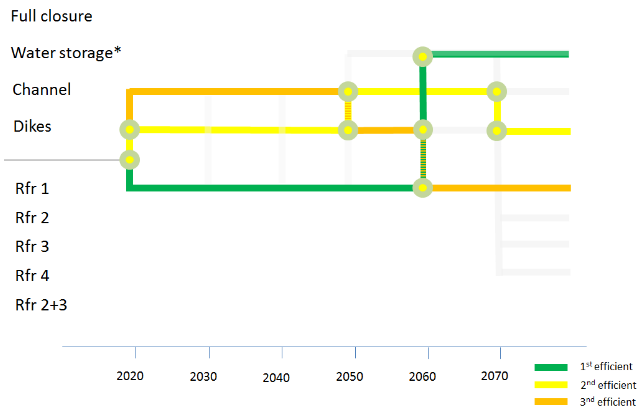
</td>
<td>

- Description and construction of the creation of efficient pathways
- In both scenarios, room for the river (small) 1 is most efficient until 2070 (rest) or 2060 (steam)
- After 2070 the construction of dikes becomes efficient in the rest scenario, while in a steam scenario this shifts to water storage in 2060.

**Efficient pathways - Rest**




**Efficient pathways - Steam**

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| Case study | Type of results | Results | Comments |
|---|---|---|---|
| Cornwall | • BCR | Benefit-cost ratio varies between 9.4 to 751.7 (2010) and 12.8 to 1080.9 (2050) depending on assumption on effectiveness.<br>Higher value of BCR very much an upper bound. 4 in 5 cases of skin cancer are preventable, so this is taken as the maximum possible benefit. We do not really know how effective the public health campaigns are – as a lower bound we estimate 1 in 100 cases are avoided. | |
| Leeds - Sustainable drainage | • NPV<br>• BCR | The net present values (NPV) and Benefit-Cost Ratios (BCR) of implementing Sustainable Urban Drainage Systems (SuDS) in 20% of the city of Leeds considering high benefit values were estimated for a period of 100 years using discount rates (DR) of 1%, 3.5% (decreasing) and 5%.<br>• The total costs for all discount rates are extremely high at £639,653,880,883, £2,013,861,981,797, and £12,932,971,606,314 respectively.<br>• The benefits have been estimated to add up to £60,025,693,027, £177,211,459,014, and £955,372,732,478 respectively. Although on the high end of the range available in the literature, benefits were not enough to outweigh the costs.<br>• These figures gave NPV of - £579,628,187,856 (- €792,119,881,524), -£1,836,650,522,783 (- € 2,509,966,604,435) and - £11,977,598,873,836 (- € 16,368,586,620,984) respectively; and very low BCR of 0.09, 0.09 and 0.07.<br>Thus, SuDS are not a cost-effective means of flood risk adaptation in Leeds, although it is important to note that some benefits have not been quantified and their inclusion in subsequent estimations might change this outcome.<br>Exchange rate GBP£ 1 = € 1.3666 from www.xe.com for January 2015. | Low, medium and high maintenance values - allow for consideration of uncertainty |

| Case study | Type of results | Results | Comments |
|---|---|---|---|
| Leeds – Ecosystem-based adaptation | • NPV<br>• BCR | The net present values (NPV) and Benefit-Cost Ratios (BCR) of implementing an ecosystem-based approach to adaptation (EBA; i.e. non-commercial woodland planting) in suitable areas (i.e. land without constraints that would contribute to flood risk reduction according to the Forestry Commission) of the Aire catchment were estimated for a period of 100 years using discount rates (DR) of 1%, 3.5% (decreasing) and 5%.<br>• The total PV costs for all DR were £715,074,908, £2,328,564,777 and £13,730,165,938 respectively.<br>• The PV benefits were significantly higher than the costs at £20,493,116,283, £72,209,214,640 and £494,072,859,908 respectively.<br>• These figures give NPV of £19,778,041,375 (€27,028,671,343), £69,880,649,863 (€95,498,896,103) and £480,342,693,970 (€656,436,325,579) respectively; and very high BCR of 28.66, 31.01 and 35.98.<br>Thus, EBA is a very cost-effective means of flood risk adaptation in the Aire catchment, although it is important to note that according to hydrological assumptions the benefits will mainly be experienced in towns upstream of Leeds closer to the measures with minimal benefits to the city of Leeds.<br>Exchange rate GBP£ 1 = € 1.3666 from www.xe.com for January 2015. | |
| Leeds - Infrastructure | • NPV<br>• BCR | The net present values (NPV) and Benefit-Cost Ratios (BCR) of implementing hard infrastructure measures for flood risk adaptation in the city of Leeds were estimated for a period of 100 years using discount rates (DR) of 1%, 3.5% (decreasing) and 5%.<br>• The total PV costs for all DR were £271,863,504, £337,647,984 and £525,892,385 respectively.<br>• The PV benefits were higher than the costs at £5,262,645,065, £13,555,471,871 and £83,950,062,874 respectively.<br>• These figures give positive NPV of £4,990,781,561 (€6,820,402,081), £13,217,823,887 (€18,063,478,124) and £83,424,170,489 (€114,007,471,390) respectively; and very high BCR of 19.36, 40.15 and 159.63.<br>Thus, hard infrastructure is a very cost-effective means of flood risk adaptation for the city of Leeds, although it is important to note that this measure has no co-benefits beyond flood risk reduction.<br>Exchange rate GBP£ 1 = € 1.3666 from www.xe.com for January 2015. | Local authorities considered several alternatives or options, these can serve to account for uncertainty. |
| South Devon Coast - Railway | • PV<br>• NPV | Business-as-usual option is most efficient<br>NPV Alternative 1: strengthening sea defences (in m EUR): between -430 and -359 (1% and 5% discount rate)<br>NPV Alternative 2: re-routing railway line (in m EUR): -133 and -250 (1% and 5% discount rate) | |

| Case study | Type of results | Results | Comments |
|---|---|---|---|
| South Devon Coast - Fluvial flooding | • PV<br>• NPV | Alternative 2 is most efficient<br>Alternative 1 also provides a positive NPV and probably gives property owners greater assurance that their houses are protected as opposed to a community wide protections measures.<br>NPV Alternative 1: Installation of domestic flood gates at 50 at risk properties (in m EUR): between 1.66 and 0.96 (1% and 5% discount rate)<br>NPV Alternative 2: Installation of sluice gates up stream to hold back flood water (in m EUR): between 1.64 and 0.97 (1% and 5% discount rate) | |
| Mental Health UK | Monetary valuation of benefits (Risk Assessment) | Average annual benefits 2040-2045 are:<br>• Reduced prescriptions 15.7 m EUR (£12.7mn)<br>• Reduced lost earnings 1871.4 m EUR (£1,473.4mn)<br>• Reduced pain and suffering 1716.1 m EUR (£1,391.3mn)<br>• Reduced mortality loss 680.1 m EUR (£551.4mn)<br>Converted using 2012 year average exchange rates (Source: HMRC 2013) | |

# 3 Summary of Results, Conclusions & Recommendations

In this section we will come back to the main objectives of this report outlined in the beginning. First, we will summarise the results from the different case studies on the economic evaluation of different adaptation options, addressing different risks (section 3.1). Here we will also discuss the comparability and transferability of these results. Second, we will draw conclusions related to the process of economic evaluation of adaptation options, i.e. on the applicability of methods, tools and data sources (section 3.2). Finally, we will provide some key recommendations for practitioners (section 3.3).

## 3.1 Summary of the case studies' evaluation results

With the guidance outlined in Annex 1 we tried to harmonize the process of economic evaluation as well as methodical aspects in order to allow for comparability as much as possible. E.g. case studies are asked to run the evaluation with discount rates of 1% and 5%, in addition to locally recommended or prescribed discount rates.

Nevertheless, costs and in particular benefits of adaptation options are highly context-specific, as they depend very much on the case study's specific risk and exposure to climate-related threats as well as the baseline scenario used, e.g. pre-existing protection, the timeframe of the evaluation, which is chosen in accordance with the lifetime of particular adaptation measures respectively stakeholder and/or decision maker needs, etc. This means that the comparability of results is still rather limited, due to site-specific context conditions.

In the following we will summarise at least some trends in the results for the different risks addressed (see also tables 2.5 and 3.1 for some figures for the different risks):

**Floods**

- In case of large cities with a high concentration of people and values exposed to flood risk, large structural flood risk mitigation measures seem to be highly efficient, compared to the business-as usual[7]. This is the case in Prague and Leeds where the flood control system is estimated to be highly efficient and also in Copenhagen, where the coastal protection system is also regarded to be highly efficient.
- But also in more rural areas structural measures such as dike solutions or sluices (South Devon) can be efficient. In the Kalajoki case study dikes turn out to be most efficient from a partial cost-benefit perspective. In the Kalundborg case study a coastal dike solution is also found to be most efficient, or at least more efficient than even more costly offshore dike solution. The Aveiro Coast CBA also shows that the bundle of measures, which tend to favour grey measures yields a positive NPV due to their effectiveness in preventing extreme events.
- But also non-structural measures can be efficient for large cities, at least in combination with structural measures. In Rotterdam, a non-structural measure (small room-for-the-river option) in combination with dike reinforcement is identified as the most cost-effective pathway until 2070. Nevertheless, also here structural options such as a pure dike solution and more structural water retention measures perform second & third until 2070 and are likely to become more cost-effective after 2060 or 2070, depending on the scenario.
- Including more intangible criteria, such as ecological criteria or impacts to other sectors, may result in structural measures such as dikes being ranked lower than just based on partial efficiency. E.g. in the Kalajoki case study dikes turned out to be most efficient from a partial cost-benefit perspective, but on the basis of a

[7] Also in the following statements on efficiency, this is always in relation to the business-as-usual. For an overview on the baseline options in the different case studies see table 2-3.

multi-criteria evaluation they are only regarded to be of secondary priority. I.e. when intangible criteria are also included in the analysis, the increase of water retention capacity of the river basin and of the recovery capacity seem to be more important, maintaining already existing measures.

- Private flood protection measures can be efficient (South Devon, Venice). However, in the South Devon river flood case study a structural solution (installation of sluice gates upstream) turned out to be even slightly more efficient than a private measure (private flood gates). However, this private measure is also highly efficient compared to the baseline and might probably give property owners greater assurance that their houses are protected than in the case of the public adaptation measure. Yet, the question of cost bearing might also be of relevance in this particular context.
- In the Venice case only one private adaptation strategy with relatively small and cheap measures turned out to be efficient. The current state of private protection as well as a full impermeabilization, i.e. a dry flood proofing of buildings, turns out to be inefficient, at least if only tangible, monetary benefits are considered. Only an adaptation strategy consisting of small adaptation measures, i.e. punctual insulation measures like barriers and pumps, etc. is efficient under these conditions. Also in this case study it is likely that the inclusion of intangible benefits would have led to better efficiency results also for the other adaptation options.
  For private flood protection the question of cost bearing might also be of relevance: If private measures are not subsidised some measures might not be affordable to households (Venice, South Devon, Cascais).
- One BASE case study gives evidence that sometimes it is more efficient to keep the “business-as-usual” than to adapt, at least from a local perspective. In the South Devon coastal railway case it turned out to be more efficient to keep “business-as-usual” and to compensate damages than to carry out costly adaptation measures. However, at it is mentioned in this case study also the spatial scale of a CBA may influence the results: In a localised case important information from the bigger picture might be missed – in this case that the Dawlish coast is not the only part of the rail line that is vulnerable and that these other vulnerabilities may provide the adaptation tipping point for rerouting.
- For pluvial flooding the Copenhagen case study shows that just maintaining the current sewage system is not efficient. In this case backflow valves and surface adaptation proves to be the most efficient solution.
- Socio-economic development may also play a critical role whether adaptation measures are efficient or not. If protected values increase fast in a high growth scenario (SSP5), investments in flood protection measures are more likely to be efficient, as also protected values and, hence, damages avoided by the adaptation measure will increase.
- When comparing different measures for flood retention, the more structural solutions such as green roofs or rainwater harvesting turn out to be much more expensive than green measures such as green corridors and rivers rehabilitation (Cascais). In the Leeds case study the greener measures, i.e. Sustainable urban Drainage Systems (SuDS) and Ecosystem-based Adaptation (EBA), were more expensive than grey infrastructure, although the former provide a multitude of co-benefits not provided by infrastructure measures.
- Institutional framework conditions, such as institutional routines and institutional complexity, may also have a strong impact on the efficiency of measures (see BASE Task 5.4). Adaptation options, which have high transaction costs (planning, negotiation and implementation costs), may turn out to be inefficient. In some cases this can be an advantage for green measures (Cascais), in other cases standard dike solutions have low transaction costs compared to more green non-structural solutions (Meyer et al. 2012).

**Heat stress & health**

- Land use-related measures have the potential to limit heat stress in cities. The Prague case study shows that increasing green areas & water areas are able to keep heat stress below a certain level. But it also shows that in case of rapid climate change (RCP 8.5) these measures are only able to keep the heat stress levels below the threshold value for a comparatively short period of time, i.e. the next 20 years.
- Conflicting results are derived with regard to green roofs as an adaptation measure to reduce heat stress. In the Jena case study this measure turns out to be efficient - at least if future benefits are given high weight by using the officially recommended, low (1.5%) or a moderate (3%) discount rate. This result is not confirmed by the assessments in the Madrid case study, where green roof solutions are estimated to be inefficient. The main reason for the poor performance of green roofs in the Iberian BASE case studies are the substantially higher costs of this adaptation measure compared to Germany. These differences can be explained by the different levels of development of market for specific adaptation technology. For Madrid it is concluded that the urban heat island effect could be reduced more effectively by tackling its causes, e.g. by reducing the use of air conditioning, than by using engineering solutions like green roofs.
- In the Jena case studies the use of large trees and light-coloured pavements prove to be very beneficial not only for the site-specific micro-climate but also for other aspects as the amenity value of public spaces. The overall effect of using non-natural water elements, e.g. fountains, was rather mixed. Their positive effects on the local micro-climate and aspects as amenity value and architectural quality did hardly outweigh the substantial investment and maintenance costs. Large-crowned urban trees turned out to be even less costly in a long-term perspective.
- The Madrid case study also shows that the heat & health warning system (HHWWS) is efficient under all scenarios and can be considered to be a low regret measure. Results show that if acclimatisation processes are not properly considered in the evaluation of HHWWS (e.g. in terms of changing critical temperature). If the heat and health warning system is set to an incorrect critical temperature, this would lead to additional costs of implementation, ranging from 25% to 60% increase.
- In the Cornwall case study a public health campaign regarding UV exposure and related skin cancer risk turns out to be highly efficient, even when a very low effectiveness of the campaign is assumed. Furthermore, the campaign is a “no-regret”-option, i.e. even without expected effects of climate change the campaign would be economically efficient. However, with climate change and population growth, the campaign will be even more efficient.
- In the UK Mental Health case study the results of the analysis suggest that prescription demand will fall under climate change, mainly because temperature increase will likely lead to a reduction in mental health problem prescription costs, which outweighs negative effects on prescription costs due to higher precipitation, cloud cover and UV.

**Ecosystem service degradation**

- In the Czech Green roof case study the “Green strategy”, prioritising nature conservation turns out to be most efficient (highest NPV for both RCPs, both discount rates, and min-max model results). Also a shared-vision adaptation strategy proves to be efficient compared to the baseline. The “red strategy” focussing on economic development is inefficient, based on the CBA conducted.

**Water quality**

- The Kalajoki water quality study shows that all agro-environmental measures analysed will become more cost effective under future climate conditions due to the expected higher input load. In the climate change (baseline) scenario the cost-effectiveness for all measures would be better than in the present state. In the period of 2021-2030 costs for reduced phosphorus will decrease by 4% and in 2051-2060 even by 21%. This is a consequence of a larger share of total loading caused by agriculture. E.g. a wetland reducing 34% of the incoming loading would retain more phosphorus (in kilograms), if the incoming loading is larger. The average reduction rate can be assumed to stay constant because it has limited effect on cost-effectiveness of the measures with KUTOVA-tool.
- Considering different agricultural adaptation scenarios the results get more diversified: For Little adaptation and Moderate adaptation scenarios so called field measures (buffer zones, winter time vegetation and perennial grass) are not as cost-effective as they are now. This is mainly because of changes in the amount of wintertime vegetation and perennial grass in these scenarios. This affects to the potential extent and cost-effectiveness of the additional area of these measures. The cost-effectiveness of wetlands, controlled drainage and optimal fertilization is better in these scenarios than under present climate conditions. This seems to be because the reduction rates stay the same in these scenarios and the loading is higher. In the Successful adaptation scenario all the measures would be more cost-effective in future than they are now. Also in this scenario the loading is higher than present. In addition, the crop distribution in this scenario is favourable for implementing buffer zones, wintertime vegetation and perennial grass.
- However, not only the currently planned mitigation measures but also a cost-effective combination of measures would struggle to achieve the current loading level under future conditions, not to mention the target level of good ecological status.

**Water scarcity**

- In the Alentejo case study the water retention landscape lakes of Tamera have proven not to be an efficient adaptation measure, yielding a negative NPV. This is mainly due to a lower than expected positive ecosystem services and high investment costs involved in the construction phases. Nevertheless, carbon storage and water purification are positive against BAU option.
- The participatory MCA in the Doñana case study elicited the different values and preferences of different stakeholder groups: Farmers Association decisions are mainly dominated by technological and profit-driven principles with preference on new water infrastructure and farming subsidies. Environmentalists showed reluctance to those options, which may result in higher economic costs and environmental impacts due to new infrastructures. Environmentalists and administration actors supported the reduction of rice cultivated area as an effective adaptation option. All the actors and the experts emphasized the important role that improved institutions could play and the need for encouraging farmers' long-term thinking by capacity building.

**Conclusions on comparability & transferability of results**

- Although trying to harmonize the process of economic evaluation as much as possible case study results remain to some degree incomparable, due different site-specific context conditions (different risks addressed, different baseline protection, different project timeframes etc.). Furthermore, it has to be considered that in many case studies bundles of measures are evaluated, which are again very case specific and therefore difficult to compare to other measures in other case studies.
- Very different results for similar adaptation measures in BASE case studies, e.g. green roof assessments in Jena, Cascais and Madrid, revealed that there are substantial costs differences for these measures across Europe. These can be explained by the different levels of development of market for specific adaptation technologies.
- These heterogeneous results demonstrate that a simple transfer of results is not scientifically sound, unless not only methods applied, but also all of the case-specific conditions are comparable. One type of adaptation option, which turned out to be efficient in one case might be highly inefficient in another case.
- On the other hand these results show that it is worth taking the effort to carry out economic evaluation processes, which are adjusted to the specific needs and context of each case. Therefore, the second and probably more important part of our conclusions is dedicated to the lessons learnt regarding the applicability of different methods and tools for the process of economic evaluation of adaptation options.

**Table 3-1: Overview costs and benefit figures for different risks addressed**

| Primary risks | Type of measure | Specific Adaptation measures | Case study | Costs | Benefits | NPV, BCR | Comments |
|---|---|---|---|---|---|---|---|
| Floods (Coastal, Fluvial, Pluvial) | Structural protection measure | Coastal protection measure, in combination with the finishing and landscaping-project | Timmendorfer Strand (Coastal) | 30.1 – 30.3 m EUR (Min – Max climate scenario) | 122 – 250 m EUR (Min – Max climate scenario) | Results for discount rate (DR) 1.5 %:<br>NPV: 92 – 220 m EUR<br>BCR: 4.1 – 8.2<br>(Min – Max climate scenario)<br>DR 1%:<br>NPV:<br>119 – 274 m EUR<br>BCR: 4.9 – 10<br>DR 5%:<br>NPV: 13 – 63 m EUR<br>BCR: 1.4 – 3.1 | Results compared to baseline option: existing coastal protection level, no-further investment |
| | | Fixed structural measures, mobile measures | Prague (Fluvial) | DR 1%: 196 m EUR<br>DR 5%: 163 m EUR | DR 1%: 2,068 m EUR<br>DR 5%: 762 m EUR | DR 3%:<br>NPV: 918 m Euro.<br>BCR: 6.7<br>DR 1%:<br>NPV: 1 872 m Euro.<br>BCR: 10.6<br>DR 5%:<br>NPV: 599 m Euro.<br>BCR: 4.7 | Results compared to baseline option: existing flood protection, level of 2002 |
| | | Dikes, sluices | Copenhagen (Coastal) | DR 3%:<br>NPC: 536 m EUR | DR 3%:<br>NPB: 2,668 m EUR | DR 3%:<br>NPV: 2,132 m EUR<br>BCR: 5.0<br>DR 1%:<br>NPV 4,963 m EUR<br>DR 6%:<br>NPV: -142 m EUR | Results compared to baseline option: existing coastal protection level, no-further investment |

| Primary risks | Type of measure | Specific Adaptation measures | Case study | Costs | Benefits | NPV, BCR | Comments |
|---|---|---|---|---|---|---|---|
| Floods (coastal, fluvial, pluvial) | Structural protection measure | Wall defences, movable weirs and island cut | Leeds (Fluvial) | DR 1%: 373 m EUR<br>DR 3.5%: 463 m EUR<br>DR 5%: 719 m EUR | DR 1%; 7,207 m EUR<br>DR 3.5%: 18,560 m EUR<br>DR 5%: 114,942 m EUR | DR 1%: NPV: 6,832 m EUR BCR: 19.36<br>DR 3.5%: NPV: 18,096 m EUR BCR: 40.15<br>DR 5%: NPV: 114,216 m EUR BCR: 159.63 | Results compared to baseline option: existing non-structural flood risk management measures |
| | | Dikes | Kalajoki | Investment costs: 4.7 m EUR<br>Costs per m: 200 EUR/m<br>Maintenance costs: 5,000 EUR/year | PVB: 7.4 m EUR | DR 3.5%: Payback time: 23.7 years | Results compared to baseline: current flood protection standards |
| | | Offshore dike with high water level locks | Kalundborg (Coastal) | Construction costs: 80.4 m EUR | 147 m EUR | . | No discounting has been conducted in the initial study, hence, no NPV and BCR figures are available |
| | | Offshore dike with locks and pumps | Kalundborg (Coastal) | Construction costs: 81.7 m EUR | 241 m EUR | . | No discounting |
| | | Coastal and river dikes, pumps and sluices | Kalundborg (Coastal) | Construction costs: 36.9 m EUR | 241 m EUR | . | No discounting |

| Primary risks | Type of measure | Specific Adaptation measures | Case study | Costs | Benefits | NPV, BCR | Comments |
|---|---|---|---|---|---|---|---|
| Floods (coastal, fluvial, pluvial) | Structural protection measure | Combination 1: Dune reinforcement, seawall, artificial nourishment.<br>Strong focus on nourishment | South Aveiro Coast | DR 3% decl.:<br>PVC: 143 – 157 m EUR | DR 3% decl.:<br>PVB: 94 – 96 m EUR | DR 3% decl.:<br>NPV: -49 – -61 m EUR<br>BCR: 0.61 – 0.66<br>DR 1% decl.:<br>NPV: -60 – -75 m EUR<br>BCR: 0.63 – 0.67<br>DR 5% decl.:<br>NPV: -41 – -52 m EUR<br>BCR: 0.59 – 0.64 | Results compared to baseline option: Beach nourishment is used when necessary and in a responsive way to extreme events. |
| | | Combination 2: Dune reinforcement, seawall, artificial nourishment.<br>Mix between 1 & 3 | South Aveiro Coast | DR 3% decl.:<br>PVC: 77 – 84 m EUR | DR 3% decl.:<br>PVB: 63 – 66 m EUR | DR 3% decl.:<br>NPV: -14 – -20 m EUR<br>BCR: 0.76 – 0.82<br>DR 1% decl.:<br>NPV:<br>-14.2 – -21.4 m EUR<br>BCR: 0.8 – 0.85<br>DR 5% decl.:<br>NPV: -13 - -19 m EUR<br>BCR: 0.73-0.8 | Results compared to baseline option: Beach nourishment is used when necessary and in a responsive way to extreme events. |
| | | Combination 3: Dune reinforcement, seawall, artificial nourishment.<br>Focus on dune reinforcement, seawall & additional breakwater | South Aveiro Coast | DR 3% decl.:<br>PVC: 54 – 55 m EUR | DR 3% decl.:<br>PVB: 80 – 81 m EUR | DR 3% decl.:<br>NPV: 25 – 27 m EUR<br>BCR: 1.46 – 1.48<br>DR 1% decl.:<br>NPV: 42 – 44 m EUR<br>BCR: 1.63 – 1.68<br>DR 5% decl.:<br>NPV: 14 – 16 m EUR<br>BCR: 1.29 – 1.33 | Results compared to baseline option: Beach nourishment is used when necessary and in a responsive way to extreme events. |

| **Primary risks** | **Type of measure** | **Specific Adaptation measures** | **Case study** | **Costs** | **Benefits** | **NPV, BCR** | **Comments** |
|---|---|---|---|---|---|---|---|
| Floods (coastal, fluvial, pluvial) | Structural protection measure | Dike reinforcement | Rotterdam | Total costs (costs of the measure & residual damage): 3,042 – 3,574 m EUR (rest and steam scenario) | (Dike reinforcement is set here as the baseline, therefore PVB is 0) | (Dike reinforcement is set here as the baseline, therefore NPV is 0) | Year of implementation: 2030<br>DR 5.5%<br>(Dike reinforcement is set here as the baseline, therefore NPV is 0) |
| | | Full closure with dams and sluices | Rotterdam | Total costs (costs of the measure & residual damage): 3,811 – 4,282 m EUR (rest and steam scenario) | . | Year of implementation: 2030<br>DR: 5.5%:<br>NPV: -769 – -708 | Results compared to the baseline option: dike reinforcement, rest and steam scenario |
| | | Strengthening sea defences | South Devon (Coast) | . | . | NPV:<br>-430 – -359 m EUR (1% and 5% discount rate) | Results compared to the baseline option: Maintaining existing sea defences, conducting repairs to damage to the rail infrastructure, cliffs and sea wall from storm events |
| | | Installation of sluice gates up stream to hold back flood water | South Devon (Fluvial) | . | . | DR 1%:<br>NPV: 1.64 m EUR<br>DR 5%:<br>NPV: 0.97 m EUR | Results compared to the baseline option: No intervention to protect the 50 at risk properties |
| | Retention & room for the river measures | Room for the River Small 1 (new and existing channels, land excavation, but in combination with dike reinforcement) | Rotterdam | Total costs (costs of the measure & residual damage): 3,033 – 3,562 m EUR (rest and steam scenario) | . | Year of implementation: 2030<br>DR 5.5%:<br>NPV: 9 – 8 m EUR<br>BCR: 1.4 – 1.6 | Results compared to the baseline option: only dike reinforcement, rest and steam scenario |

| Primary risks | Type of measure | Specific Adaptation measures | Case study | Costs | Benefits | NPV, BCR | Comments |
|---|---|---|---|---|---|---|---|
| | | Retention on agricultural land (dam & compensation of farmers) | Holstebro | Dam construction costs: 3 m EUR<br>Payment to farmers: 250 – 447 EU/ha/yr.) | Yearly avoided damages:<br>93,000 EUR/yr. | DR 1%:<br>NPV:<br>1.36 – 2.95 m EUR (SSP2)<br>3.97 – 5.56 m EUR (SSP5)<br>DR5%:<br>NPV:<br>-1.4 – -2.0 m EUR (SSP2)<br>-0.9 – -1.5 m EUR (SSP5) | Results compared to the baseline option: Current protection levels are maintained |
| | | Sustainable Urban Drainage | Leeds (Fluvial) | DR 1%:<br>874 bn EUR<br>DR 3.5%:<br>2,754 bn EUR<br>DR 5%:<br>17,690 bn EUR | DR 1%: 82 bn EUR<br>DR 3.5%: 242 bn EUR<br>DR 5%: 1,307 bn EUR | NPV:<br>DR 1%:<br>-793,247 bn EUR<br>DR 3.5%:<br>-2,513 bn EUR<br>DR 5%:<br>-16,412 bn EUR<br>BCR:<br>DR 1%: 0.09<br>DR 3.5%: 0.09<br>DR 5%: 0.07 | Results compared to baseline option: existing non-structural flood risk management measures<br>Note: Benefits are considered incomplete as some data was unavailable. |

| Primary risks | Type of measure | Specific Adaptation measures | Case study | Costs | Benefits | NPV, BCR | Comments |
|---|---|---|---|---|---|---|---|
| | | Woodland planting & management | Leeds (Fluvial) | DR 1%:<br>977 m EUR<br>DR 3.5%:<br>3,184 m EUR<br>DR 5%:<br>18,780 m EUR | DR 1%:<br>28,050 m EUR<br>DR 3.5%:<br>98,807 m EUR<br>DR 5%:<br>676,131 m EUR | NPV:<br>DR 1%:<br>27,068 m EUR<br>DR 3.5%:<br>95,627 m EUR<br>DR 5%:<br>657,305 m EUR<br>BCR:<br>DR 1%: 28.66<br>DR 3.5%: 31.01<br>DR 5%: 35.98 | Based on an area of $44km^2$ recommended by the Forestry Commission for the Aire catchment; only broadleaf woodland planting for biodiversity and carbon goals was considered, but conifer woodland for timber is an option Results compared to baseline option: existing non-structural flood risk management measures |
| Floods (coastal, fluvial, pluvial) | Private protection measures | Installation of domestic flood gates at 50 at risk properties | South Devon (Fluvial) | . | . | NPV:<br>DR 1%:<br>1.66 m EUR<br>DR 5%:<br>0.96 m EUR | Results compared to the baseline option: No intervention to protect the 50 at risk properties |
| | | Full impermeabilization (dry flood proofing) of private buildings | Venice | PVC: 352 m EUR | PVB:<br>DR 1%:<br>108 – 109 m EUR<br>DR 5%:<br>52 – 54 m EUR | NPV:<br>DR 1%:<br>-242 – -244 m EUR<br>DR 5%:<br>-298 – -299 m EUR | No intangible benefits (reduction of stress caused by floods, etc. are considered among the benefits) Results compared to the baseline option: No private protection measures at all |

| Primary risks | Type of measure | Specific Adaptation measures | Case study | Costs | Benefits | NPV, BCR | Comments |
|---|---|---|---|---|---|---|---|
| | | Punctual insulation measures like barriers and pumps (wet flood proofing), etc. to protect private buildings | Venice | PVC: 40 m EUR | PVB:<br>DR 1%:<br>62 – 63 m EUR<br>DR 5%:<br>30 – 31 m EUR | NPV:<br>DR 1%:<br>22 – 23 m EUR<br>DR 5%:<br>-9 – -10 m EUR | No intangible benefits (reduction of stress caused by floods, etc. are considered among the benefits) Results compared to the baseline option: No private protection measures at all |
| | Reduction of exposure and vulnerability | Re-routing railway line | South Devon (Coast) | . | . | NPV:<br>DR 1%:<br>-133 m EUR<br>DR 5%:<br>-250 m EUR | Results compared to the baseline option: Maintaining existing sea defences, conducting repairs to damage to the rail infrastructure, cliffs and sea wall from storm events |

| Primary risks | Type of measure | Specific Adaptation measures | Case study | Costs | Benefits | NPV, BCR | Comments |
|---|---|---|---|---|---|---|---|
| Heat stress, health | Structural | Extensive green roof | Jena | Additional installation costs compared to tar-gravel roof cover: 15 / 20 /25 EUR/m$^2$<br>Maintenance costs: Extensive green roof: 1 EUR/m$^2$ p.a. (1st year), 0.5 EUR/m$^2$ p.a. (following years) Tar-and-gravel roof: 0.2 EUR/m$^2$ p.a.<br>Rehabilitation costs (removal, sealing): Extensive green roof: 55 EUR/m$^2$ (end of 40th year) Tar-and-gravel roof: 45 EUR/m$^2$ (end of 20th year), 35 EUR/m$^2$ (end of 40th year)<br>Stormwater fee (Jena): Tar-and-gravel roof: 0.72 EUR/m$^2$ Green roof: 0.29 EUR/m$^2$ p.a. | Habitat creation value 0.035 EUR/m$^2$ p.a. (40 years, 1.5%)<br>Energy cost savings: 0.25 EUR/m$^2$ p.a.<br>Stormwater management infrastructure savings: 7.50 / 9 / 10.50 EUR/m$^2$<br>Carbon sequestration: 0.033 EUR/m$^2$ p.a. | NPV (40 years, 1.5%, cost differences and stormwater fee savings): 0.07 – 0.32 EUR/m$^2$ p.a. (most to least expensive green roof)<br>NPV (40 years, 1.5%, cost differences and stormwater fee savings, private stormwater management savings, energy cost savings): 0.52 – 0.70 EUR/m$^2$ p.a. (most to least expensive green roof)<br>Public benefits are rather low<br>Habitat creation: 0.03 EUR/m$^2$ p.a. resp. one-time 1.39 EUR/m$^2$ Carbon sequestration: 0.03 EUR/m$^2$ p.a.<br>NPV (3%, CD & SFS): most expensive green roof not efficient<br>NPV (5%, CD & SFS): only least expensive green roof efficient | Results compared to the baseline option: a typical tar-gravel roof cover |

| Primary risks | Type of measure | Specific Adaptation measures | Case study | Costs | Benefits | NPV, BCR | Comments |
|---|---|---|---|---|---|---|---|
| Heat stress, health | Structural | Green roof | Madrid | Additional costs compared to traditional roof cover (20% Green roof, SSP2)<br>DR 2%:<br>PVC (low):<br>4,072 m EUR<br>PVC (average):<br>11,296 m EUR<br>PVC (high):<br>19,906 m EUR<br>DR 5%:<br>PVC (low):<br>3,016 m EUR PVC (average):<br>9,057 m EUR<br>PVC (high):<br>15,807 m EUR | Total benefits (20% Green roof, SSP2/RCP4.5)<br>DR 2%:<br>PVC (low):<br>1,747 m EUR<br>PVC (average):<br>4,436 m EUR<br>PVC (high):<br>8,671 m EUR<br>DR 5%:<br>PVC (low):<br>654 m EUR<br>PVC (average):<br>1,669 m EUR<br>PVC (high):<br>3,277 m EUR | The benefit cost ratios present a large variability for the different green roof scenarios: from almost 0 to 3.5. The profitability of green roof very uncertain. See Annex 3 for more results. | The model is subject to thresholds and size effects. So, see Annex 3 for results with other green roof scenarios, the other socio-climatic scenario and other discount rates |
| | | Light-coloured pavements | Jena | Additional investment costs compared to ordinary pavement: 1 EUR/$m^2$ | | | |

| Primary risks | Type of measure | Specific Adaptation measures | Case study | Costs | Benefits | NPV, BCR | Comments |
|---|---|---|---|---|---|---|---|
| | Reduction of exposure and vulnerability | Heat health watch warning system (Non-structural, awareness and alert) | Madrid | Total average discounted costs (2020 – 2100):<br>RCP4.5, SSP2<br>DR 0% – 3%:<br>No acclim:<br>404 – 364 in m EUR<br>Acclim:<br>499 – 411 in m EUR<br>RCP8.5, SSP5<br>DR 0% – 3%:<br>No acclim:<br>497 – 405<br>Acclim:<br>821 – 434 | Total average discounted benefits (2020 – 2100):<br>RCP4.5, SSP2<br>DR 0% – 3%:<br>No acclim:<br>3,602 – 1,140<br>Acclim:<br>3,561 – 1,134<br>RCP8.5, SSP5<br>DR 0% – 3%:<br>No acclim:<br>5,968 – 1,527<br>Acclim:<br>6,159 – 1,512 | Average BCR (2020 – 2100):<br>RCP4.5, SSP2<br>DR 0% – 3%:<br>No acclim: 8.90 – 3.13<br>Acclim: 7.13 – 2.76<br>RCP8.5, SSP5<br>DR 0% – 3%:<br>No acclim: 12 – 3.77<br>Acclim: 7.50 – 2.74 | Higher costs in RCP8.5 because of more days with max daily temp>Tcrit. Higher costs with no acclimatisation because of additional days of activation of the system though not necessary. See Annex 3 for more details. Higher benefits in RCP8.5 because of higher health risks (see Annex 3).<br>BCR for all scenarios bigger than 1. Substantial health benefits expected in relation to costs. |

| Primary risks | Type of measure | Specific Adaptation measures | Case study | Costs | Benefits | NPV, BCR | Comments |
|---|---|---|---|---|---|---|---|
| | | Public health campaign: Awareness raising | Cornwall | 0.68 m EUR per year | . | Annual BCR varies between 9.4 – 751.7 (2010) and 12.8 – 1080.9 (2050) depending on assumption on effectiveness | It is not really known how effective the public health campaigns are. The Higher value of BCR very much an upper bound. 4 in 5 cases of skin cancer are preventable, so this is taken as the maximum possible benefit. As a lower bound it is assumed that 1 in 100 cases are avoided. |
| Heat stress, health | Nature-based | Trees | Jena | Costs per tree (incl. planting)<br>Small-crowned:<br>860 EUR<br>Large-crowned:<br>860 EUR<br>Tree care costs p.a.<br>Small-crowned:<br>Year 1 – 5: 50 EUR<br>Year 6 – 40: 20 EUR<br>Large-crowned:<br>Year 1 – 5: 50 EUR<br>Year 6 – 45: 30 EUR<br>Year 46 – 80: 80 EUR | | Large-crowned trees slightly less costly (procurement, planting, replanting, care) than small-crowned tree in the long-term perspective<br><br>NPC (82 years, 1.5%):<br>Large-crowned tree: 2,121 EUR (onetime) resp. 25.87 EUR p.a.<br>Small-crowned tree: 2,254 EUR (onetime) resp. 27.49 EUR p.a. | |
| | | Façade greening | Jena | 50 – 140 EUR/$m^2$<br>13 EUR/m | | | |

| Primary risks | Type of measure | Specific Adaptation measures | Case study | Costs | Benefits | NPV, BCR | Comments |
|---|---|---|---|---|---|---|---|
| Ecosystem degradation | Non-structural | Sustainable forest management | Green roof | No figures for single measures available | No figures for single measures available | Only figures for bundles of measures available | |
| | | Peat land and water course restoration | Green roof | No figures for single measures available | No figures for single measures available | Only figures for bundles of measures available | |
| Ecosystem degradation | Non-structural | Enhancement of ecosystem resilience, i.e. an enlargement of core protection zones | Green roof | No figures for single measures available | No figures for single measures available | Only figures for bundles of measures available | |
| Water quality | | Buffer zones (different slopes)<br>Small constructed wetlands (different % of fields)<br>Medium constructed wetlands (different % of fields)<br>Large constructed wetlands (different % of fields)<br>Winter time vegetation cover (different slopes)<br>Perennial grass (different slopes)<br>Controlled drainage<br>Optimal fertilization | Kalajoki river basin | | | All measures will become more cost effective in future due to expected higher input load.<br>In 2021-2030 costs for reduce the phosphorus load will decrease by 6% and in 2051-2060 by 22%. Cost-effectiveness of so-called field measures (buffer zones, winter time vegetation and perennial grass) decreases and for wetlands, controlled drainage and optimal fertilization increase compared to now for Little and Moderate adaptation scenarios. | |

| Primary risks | Type of measure | Specific Adaptation measures | Case study | Costs | Benefits | NPV, BCR | Comments |
|---|---|---|---|---|---|---|---|
| Water scarcity | 1. Technological<br>2. Organizational<br>3. Governance | 1. Water recirculation, flow meters, laser levelling, change of varieties, additional water infrastructure.<br>2. Reduction of cultivated surface, increase monitoring of water use, setting irrigation turns<br>3. Improve transparency, increase coordination between institutions, increase scientific research | Doñana | 200 m EUR | 20% of projected avoided damage on the environment were not estimated | | |

## 3.2 Conclusions with regard to the applicability of evaluation methods, tools, models, data sources

**Application of evaluation methods**

**CBA**

- The applicability of the CBA approach largely depends on the availability of models to produce the necessary monetary input data.
- The BASE case studies show that this is quite often the case for coastal, fluvial and pluvial flood damage estimations (Rotterdam, Venice, Timmendorfer Strand, Aveiro coast, Copenhagen, Kalundborg, South Devon, Leeds). In this decision making context the application of CBA is quite frequent. However, the BASE case studies also show that the monetary damage estimation is often limited to tangible damages (direct or indirect). Intangible effects such as ecological effects or health effects are rarely considered in monetary terms (Rotterdam, Prague). This is an observation which is not only valid for BASE case studies, but which is also supported by literature (Meyer et al. 2013). Methods for the monetisation of intangible effects, such as Contingent Valuation, Choice Modelling, Travel Cost Approach and Hedonic Pricing are available, but are so far rarely applied in practice, also due to the high efforts and resource requirements.
- This is also true for the other risks considered in the BASE case studies: heat stress, water quality, eco-system services. The effect of adaptation is often of an intangible nature, i.e. non-market goods are affected. Methods are available to monetise these effects, e.g. the InVEST model for the evaluation of ecosystem services (Green roof case study, Alentejo). This approach can be recommended in the cases where the implementation of ecosystem-based adaptation measures is considered. Still, it can be seen that the benefit-related figures obtained by using InVEST are relatively low and almost negligible when compared to the much easier to obtain cost-related figures.
- Generally such intangible effects are still more difficult to evaluate in monetary terms. That is one of the reasons why alternative evaluation approaches such as CEA (Kalajoki water quality) or MCA are used (Jena, Kalajoki flood risk, Copenhagen, Cascais).
- Another reason is that monetisation of intangible effects is not always needed or even advisable, if results are to be considered in decision-making processes. The nature and level of detail of the figures used for the BASE assessments have to be in line with the existing formal and informal decision making frameworks. E.g. while monetisation is mandatory in many decision processes in the UK, it would be unusual in German spatial planning processes or in a Finnish strategic flood risk management planning.
- The Madrid case study shows that for heat stress some of the effects can be measured in monetary terms and included in a CBA. However, "the monetary valuation of the services presents the usual challenges when services are intangible and when limited access to data makes the use of a proxy necessary" (Madrid case study).
- The Cornwall case study demonstrates how skin cancer cases can be monetised, based on a treatment cost approach, and how these figures can be included in a CBA framework to estimate the efficiency of public health campaigns.
- A partial CBA focusing on the tangible, monetary impacts of climate change might underestimate the benefits of adaptation by neglecting intangible effects (Venice, Leeds SuDS).

- When conducting a CBA it should be considered how the boundaries of the analysis in terms of what measures, costs, and benefits to include and not include may impact upon the final results (South Devon).
- In the Prague case study the relation between objective of the evaluation, assessment approach chosen and the level of detail of the CBA and the flood damage evaluation approach is discussed, mentioning the trade-off between accuracy and effort (see also section 1.2): "the main lesson is probably the fact that it all depends on the input data and their quality. In our case it would not be feasible to undergo an in-depth evaluation because the extent of the study would be enormous and way beyond the scale of this project. On the other hand, we believe that for our purposes the method was perfectly appropriate."

**MCA (and its relation to CBA)**

- CBA and MCA can complement each other: CBA can be used for tangible criteria to analyse at least the partial efficiency and MCA can be applied to complement the evaluation with other non-monetary criteria (Jena, Rotterdam, and also for the Prague case study it is mentioned that such an addition would be desirable).
- CBA and MCA can complement each other also in an iterative way. E.g. in Copenhagen CBA is used for the general test whether the coastal protection solution is efficient or not, and MCA is then applied in a second, more participatory evaluation round for the evaluation of different design variants of the main coastal protection option chosen.
- In the Kalajoki flood risk management case it is the other way around: It is stated that on the level of a strategic document like the flood risk management plan, in which a pre-feasibility study of potential measures is conducted, a detailed CBA is not necessary (see Kalajoki case study). It is argued that applying CBA and CEA include the risk of neglecting other important criteria, such as political, social and environmental issues. This particularly true when dealing with multi-objective adaptation options, such as natural water retention measures or water level regulation.

**CEA**

- The application of a CEA is advisable when adaptation options are compared which have in principle the same main, non-monetary target effect, e.g. cost to reduce P concentrations in the Kalajoki water quality study. The combination of different tools from SYKE in this case study shows a sophisticated way how the cost-effectiveness of adaptation measures can be analysed not only for the current situation buts taking into account climate and socio-economic change.
- A new kind of assessment approach combining a CEA with the Dynamic Adaptation Pathway approach is applied in the Rotterdam case study. By identifying the least costly way of fulfilling certain flood protection standards over time and under different climate and social-economic scenarios, this case study provides an innovative example for how to include economic considerations in the development of dynamic adaptation pathways.
- The CEA study in Holstebro provides an innovative approach how to elicit the cost of flood retention on agricultural land by means of a choice modelling approach.

**PBCA**

After running the PBCA tool in three separate workshops with more than 40 participants the key findings regarding the methodology are:

- It is more about the process than the result itself. People engaged seriously in technical and also ethical/moral debates but then disregard the final net present value;
- In the context of the PCBA workshops some participant disclosed negative time-preferences for certain measures. This led to the use of negative discount rates for measures such as Reforestation, Green Corridors and the Re-naturing of Cascais water streams. This somewhat counterintuitive intermediate result has been confirmed by other empirical studies (Bell et al, 2003).
- Simple to use and understand, mainly if there is good facilitation/focalization of the debate;
- The introduction of the time-factor and the inherent challenges involved with the use of discount rates enriches the debate and contributes significantly to the usefulness and maturation of the tool;
- Inexpensive to use and implement as it can be applied in the context of an existing workshop and represent a 1-hour add-on to the program with minimum marginal costs;
- Strong logical and methodological links exists between MCA, PBCA and then CEA/CBA as MCA can be used to filter down may variables to a top 3 or 5 priorities, PBCA can help to zoom in those pre-selected, namely by naming the most relevant impacts, and CEA/CBA be used to quantify those impacts.

**Other methods**

- Other evaluation methods mentioned in the introduction such as RDM and ROA have not been applied in the BASE case studies. This is due to their higher complexity and computational effort, which makes them difficult to be applied in relatively small, local case studies. However, due to their ability to explicitly address uncertainties in the evaluation an application would be advisable in particular for bigger long-term investment decisions under deep uncertainty.

**Decision support tools**

- In the BASE case studies all the MCAs are carried out with the tool PRIMATE (Jena, Copenhagen, Cascais (Rotterdam), (Prague)). The CEA tool KUTOVA is used in the Kalajoki case study and the Planning Kit DPRD is applied for the economic evaluation of pathways in the Rotterdam case (see section 0 for a brief description of the tools).
- As stated in the Guidelines in Annex 1 there are also a lot of decision support tools available which support CBA, MCA or other evaluation approaches.

**Data sources (climate data, socio-economic data, cost and benefit data)**

- For the Prague case study it is concluded that “the main lesson is probably the fact that it all depends on the input data and their quality” and also the authors of the Kalajoki case study state that “our case study revealed that it is of a key importance to have a realistic assessment of the benefits of the measures, otherwise the results are not reliable” (Kalajoki). These two statements from different BASE case study underpin the argument that good data sources are a crucial prerequisite for sound evaluations.
- The most important source for cost-related data in the BASE case studies are official sources, such as statistics, plans etc. A close cooperation with local stakeholders is therefore advisable, e.g. to obtain data which is not publicly available (see e.g. Green roof, Prague, Leeds). Additionally, data from scientific sources,

e.g. literature, private consultancies or other experts is used. One case study evaluated the cost data for compensation payments to farmers based on choice experiments (Holstebro). In the Rotterdam case study dike reinforcement costs are based on modelling results.

- Benefit-related data often comes from impact assessment models. I.e. by calculating the impacts with and without the planned adaptation options, the benefits in terms of damage reduction can be estimated. The BASE case studies offer several good examples of the application of various impact assessment tools, such as the InVEST model for ecosystem services (Green roof, Alentejo), the Planning Kit DPRD for flood risk assessment and management (Rotterdam), the URBAHT tool for heat stress (Jena, Prague), the WAAPA model for water availability (Doñana case study) and the VEMALA model for nutrient loading (Kalajoki). The different models and tools are described in detail in section 0.
- As for the cost data official sources, e.g. guidelines, statistics, maps and plans, but also scientific literature and databases of insurance companies are important sources of benefit-related data. In addition, benefits are also estimated by the use of household surveys (Kalajoki), stakeholder workshops (Kalajoki, Copenhagen) or expert interviews (Jena, Rotterdam, Kalajoki).

**Different possibilities to deal with uncertainties**

- The BASE case studies show that economic evaluations of adaptation options have to deal with uncertainties of different types (uncertainties regarding climate and socio-economic change, model and data uncertainties, uncertainties regarding stakeholder preferences and values).
- The common way to deal with uncertainties regarding climate or socio-economic change is to use scenarios. By conducting evaluations for different climate and socio-economic scenarios it can be shown how different adaptation options perform under different potential future developments (see e.g. Rotterdam, Green roof, Madrid). Thereby, robust options can be identified, i.e. options, which perform well under different scenarios.
- If the effectiveness of certain measures is uncertain, upper and lower bounds can be estimated (see e.g. Cornwall case study on the effectiveness of a public health campaign).
- Sensitivity analysis is applied e.g. in the Copenhagen, Prague and Madrid case studies to show the effects of changes in the input data or different discount rates on the overall evaluation results.
- Another option to deal with model and data uncertainties is Monte Carlo analysis (applied in the South Devon and Jena case studies). The PRIMATE tool (see section 1.4.8) comes with this feature. Uncertainties in the input data can be considered by means of score ranges or probability distributions. By running the CBA or MCA several times, taking random samples of this data, uncertainties in the input data are also reflected in the results, providing a ranking probability of the different options.
- As stated before, approaches such as RDM and ROA also provide the possibility to explicitly address uncertainties in the evaluation.
- Varying preferences of different decision-makers and/or stakeholders with regard to the various criteria to be used for a MCA can also be considered by the PRIMATE tool. It uses particular sets of criteria weights for each stakeholder group when performing the analysis (e.g. Jena case study).

## 3.3 Key recommendations

In this report we provided practical guidance on economic evaluation of adaptation options and presented empirical examples for assessing the cost and benefits of different types of adaptation options (addressing the BASE objectives 1, 2 and 4). Running the common methodical guidance in several European case studies provided many good-practice examples on how to conduct economic evaluation of adaptation options for different kinds of risks, different kinds of adaptation options etc. (see also Annex 3 for the detailed case study descriptions). However, although methodical aspects have been harmonised as much as possible, case study results remain to some degree incomparable, due different site-specific context conditions. The case study results demonstrate that a simple transfer of results is not scientifically sound, unless not only methods applied, but also all of the case-specific conditions are comparable.

For us it therefore seems to be more important to provide guidance on how to conduct an economic evaluation of adaptation options. The stepwise guidance document (provided in Annex 1) has proven to provide such support for the case studies, and can be recommended as guidance for municipalities and/or consultancies, that want to apply economic evaluations of adaptation options.

The following key recommendations are therefore also mainly dedicated to the process of conducting an economic evaluation of adaptation options.

1. When starting an economic evaluation of adaptation options it is advisable to follow one of the various existing guidance documents (see section 1.1 for an overview on different guidance documents at different levels and for different sectors). The guidance document provided in Annex 1 focuses particularly on climate change adaptation at the local level.
2. The transferability of results from other studies is limited. Nevertheless for a pre-selection of options it makes sense to review the literature for similar studies in comparable regions and similar sectors to get an idea which type of measures are likely to perform well under which conditions.
3. The choice of an appropriate evaluation method largely depends on several factors (see also table 3.2 & PROVIA 2013):
    a. Objective of the study and the required level of detail:
    For pre-feasibility studies on a strategic level it is fully sufficient to conduct relatively simple MCAs, approximate CBAs or CEAs. For detailed investment decisions detailed CBAs, preferably in combination with participatory MCAs or PBCAs would be advisable. For very big investments under deep uncertainty also approaches such as RDM and ROA should be taken into consideration.
    b. Number and type of evaluation criteria:
    If there is only one target criterion a CEA might be sufficient, but in a multi-objective decision situation a comprehensive CBA or MCA should be chosen.
    c. Data availability:
    A CBA is more easily to conduct when there is already a lot of monetary data available or there are models at hand to generate it. If this is not the case (and the objective of the study does not justify to purchase or generate such data) it is more advisable to carry out a MCA than to stick to a partial CBA, which neglects important criteria. RDM and ROA approaches require quantifiable information on the uncertainties of the input data.

**Table 3-2: Factors influencing the choice of an appropriate evaluation method**

| **Factor** | **Range** | |
|---|---|---|
| **Objective** | **Pre-feasibility study** | **Investment decision** |
| | Simple CEA, CBA or MCA | Comprehensive CBA, participatory MCA, RDM |
| **Investment costs** | **low** | **high** |
| | Simple CEA, CBA or MCA | Comprehensive CBA, participatory MCA, RDM |
| **Uncertainties** | **low** | **high** |
| | Simple CEA, CBA or MCA | CBA or MCA with Monte-Carlo simulation, RDM, ROA, DAP |
| **Number of evaluation criteria** | **low** | **high** |
| | CEA, partial CBA | Comprehensive CBA, MCA |
| **Data availability** | **low** | **high** |
| | MCA | CBA, RDM |

4. There are already many impact assessment tools out there, in particular for flood risk assessments, but also for assessments regarding heat stress, ecosystem services, water availability and water quality. It is often more efficient to rely on existing models (and buy them in) than to try to generate own models and/or data. However, the transferability of models is sometimes also limited. It is advisable to search for a model, which is adapted to the local, regional or national framework conditions or which can be easily calibrated with local parameters.

5. No matter how sophisticated models are, there are always uncertainties inherent in the results. Such uncertainties (related to climate and socio-economic change, input data, model results, or stakeholder preferences) should be considered in the evaluation process and made transparent in the results.

6. From the recent trends not only with CBA but mainly with MCA and CEA we argue that not only complementarity between different tools but also the increasing use of participatory methodologies is fundamental when dealing with uncertainty, with complexity, with growing demand for transparency in public decision-making processes and the need to engage local communities in adaptation (see BASE Task 5.3).

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# 4 Annex 1: Guidance for economic evaluation of adaptation options

Volker Meyer (UFZ), Oliver Gebhardt (UFZ), Jenny Tröltzsch (EI), Aline Chiabai (BC3), Anil Markandya (BC3), Filipe Alves (FFCUL), Timothy Taylor (EU), Nina Becker (UFZ), Clemens Heuson (UFZ)

## 4.1 Introduction

The main objective of this Annex is to provide guidance for on economic evaluation of adaptation measures. This stepwise procedure was originally developed by UFZ (Gebhardt et al., 2012, BMVBS, 2013) as guidance for German municipalities to evaluate adaptation options. As such, it aims to be quite simple to apply, accounting for a great diversity in data availability and uncertainties. It does not recommend one evaluation method but gives room for several ones, such as cost-benefit analysis, cost-effectiveness analysis and multi-criteria analysis.

The procedure is adjusted in the BASE project and tested in several case studies (see chapter 2 and Annex 1). The stepwise evaluation procedure is briefly illustrated in section 5.1.1. Each step is then described in the following sections, illustrated by a case study example. A further case study example is described in section 5.7.

As this guidance is primarily addressing ex ante evaluation of adaptation options. Nevertheless, it can also be applied in retrospective cases for analysing the efficiency of adaptation measures and stakeholder preferences from an ex post perspective.

## 4.2 Stepwise procedure for the economic valuation and prioritization of adaptation measures

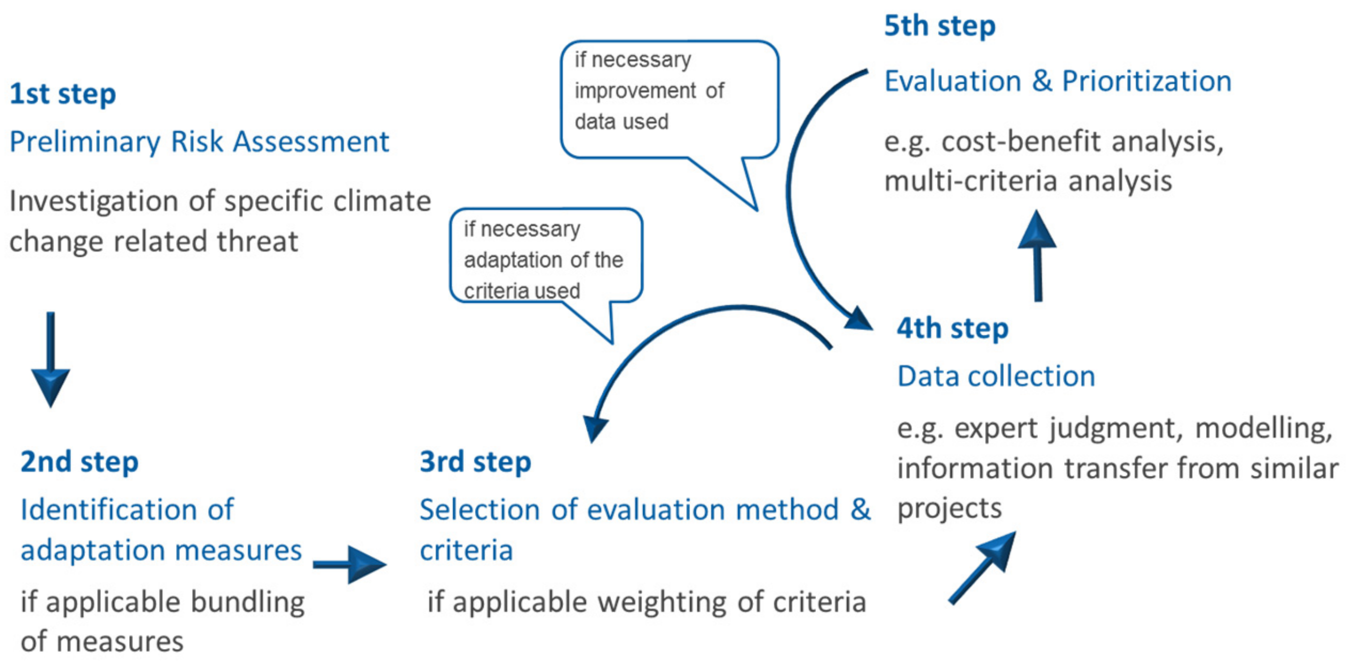


**Figure 4-1: Steps of the economic evaluation process**

Figure 4-1 shows the five steps of the evaluation process. These steps will be described in the following and illustrated by a case study example.

Depending on data availability, flexible adjustments of the process are possible:

- Adjustment of evaluation criteria (feedback loop step 4 to step 3)
- Improvement of data basis, e. g. by reducing uncertainties, if prioritization results are ambiguous (feedback loop step 5 to step 4).

**Example: Heat in the city – short introduction**

- Redevelopment of a central urban square (“Eichplatz”) in Jena, Germany
- Centrally located square in the city centre of Jena with a total area of 1.6 ha
- Currently mostly black asphalt sealed surface area (parking area) with a low share in green areas

**Figure 4-2 Present parking area on the “Eichplatz” square**

- Measures to reduce heat stress are to be integrated in the redevelopment of the area.
- Objective: Comparison of potential measures regarding various aspects, which are of relevance to local decision-makers.

### 4.2.1 Step 1: Preliminary risk assessment

***Problem definition***

For problem definition the following questions should be answered:

- Which problems already exist, what is/are the current risk/s? Does your case study have a single or multi impact focus?
- What is at risk? Which assets are of relevance within the geographic context of our study?
  - This includes land values, buildings, infrastructures, natural capital, and social capital. How has the value of those assets evolved in the past and why?
  - Which areas are affected? If possible provide maps and sectorial disaggregation of impacts.
  - Which sectors are affected? Does your case study have a single or multiple sector focus?
- How do these risks presumably change due to climate and socio-economic change? How do asset at risk and their value evolve with these changes? Why? Compare with surrounding environment and take into consideration the new climate change and socio economic scenarios.
- What timeframes are considered?

***How to do this***

- Existing problems: analysis of past events
- Current risk situation: Refer to existing risk or vulnerability studies
- Assets at risk, including areas and sectors: asset definition and asset mapping
  - Identify assets, which already do exist within the geographic context of your study. This includes land, buildings, infrastructures, natural capital, and social capital. Depending on the nature of the assets (private, public) all information should be available in companies' financial reports, public assets reports, and land value estimations, e.g. by banks. If data regarding natural and social capital is not available simple mapping might be sufficient.
  - Identify key assets for the economic, natural and social resilience of the community and key stakeholders who are legally responsible and/or have vested interests with regard to the respective area. This can be done through inquiries to the local community.
- Expected changes in risk due to climate change and thus assets at risk:

Refer to existing studies on climate change impacts and vulnerabilities; plus new IPCC AR5 climate scenarios, and socio-economic scenarios.

If such studies are not available:

  - Which models provide results for your case studies?
  - Own modelling/risk assessment, if possible.
  - Interviews with experts on expected climate change impacts.

*Example, step 1*

***Preliminary risk assessment***

- Jena is particularly exposed to heat stress and flooding due to its geographic location in the Saale valley surrounded by shell limestone slopes.
- Highest level of thermal stress experienced in the city centre during the summer months.
- Increase of mean annual temperature of 1,2K over the past 100 years.
- Heat stress is expected to increase on the basis of climate projections:
    - Projected increase in mean annual temperature.
    - Projected increase in number of days with $temperature_{max} \geq 30°C$ from 10-12 days/year to 19-20 days/year until 2050 (STAR, WETTREG2010)

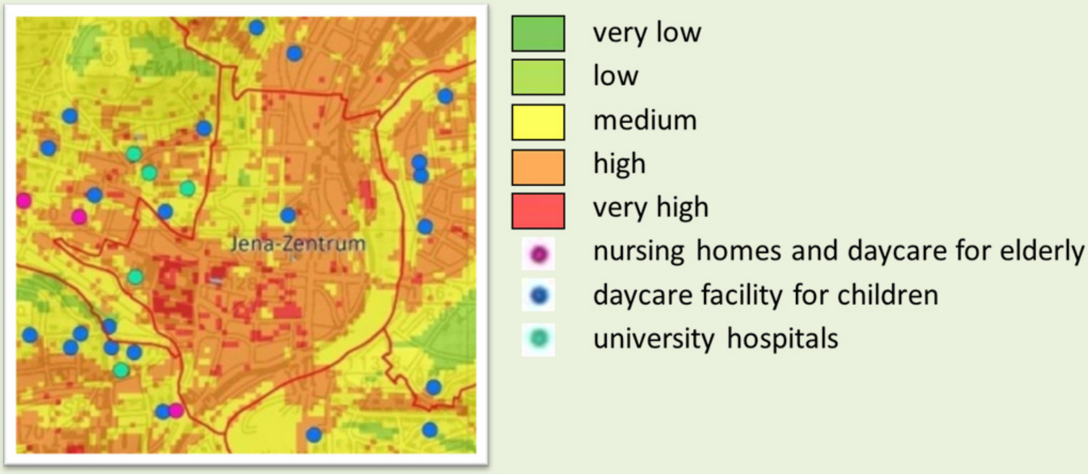


**Figure 4-3 Risk of heat stress in the city area of Jena based on the degree of sealed surface, building structure, global radiation, local and regional wind system**
Source: ThINK (2011)

### 4.2.2 Step 2: Identification of adaptation measures (and pathways)

***Objectives of measures***

- Before designing specific measures the objectives of adaptation in the case study should be described:
    - What is the primary objective of adaptation?
      (e.g. flood risk reduction, heat stress reduction, …)
    - Are there other objectives to be considered?
    - The different objectives are the basis for the development of evaluation criteria (cf. step 3a)

***Potential measures***

- To gather important potential measures the following questions should be considered:
    - Which measures could fulfil the objective(s) (short-term, long-term measures)?
    - Are there adaptation measures already in place?
    - Are there already other measures from distinct planning procedures in place, which could implicitly contribute to the adaptation objective(s)?
    - Which measures may provide benefits also in the absence of climate change or climate variability? Distinguish no regret, low regret and regret options.
    - Which measures may result in co-benefits that are only indirectly linked with the primary adaptation objective? What co-benefits could be achieved?
- Appropriate measures should be selected in close cooperation with experts from the different sectorial planning bodies, such as: department of city/regional administration, etc.
- Measures should be described in detail and clearly distinguished from alternative options.
- If possible, displaying the measures on a map helps to better describe the measures and to show if measures are mutually exclusive.

***Baseline option***

- In particular for cost-benefit analysis (see step 3), a baseline option needs to be defined. All other measures are compared to that baseline option, i.e. benefits and costs are always related to this baseline option.
- The typical baseline option is “business-as-usual”, i.e. it is assumed that e.g. the current protection level is maintained for the evaluation timeframe.

***Bundles of measures***

- Depending on the problem and measures selected it can be reasonable to build bundles of complementary measures. Bundles should consist of complementing measures, which can belong to the same sector, but can also consist of measures of different sectors. Furthermore, the measures can have the same adaptation target, e.g. reducing soil erosion in agriculture by intercropping and buffer strips. But if quite general adaptation targets exist such as increasing the climate resilience of a city, the bundle of measure can also focus on different adaptation targets.

***Adaptation pathways***

- See dynamic adaptive pathways approach by Haasnoot et al. (2013), requires the definition of adaptation tipping points and "sell-by" dates of measures.

*Example, step 2*

***Objectives of the measures***

- Overall objective: Increase wellbeing at Jena's central square
- Main objective: Heat stress reduction within the context of the redevelopment of a central urban square in Jena ('Eichplatz')
- Further objectives:
  - Attractive design of the square
  - Consideration of other aspects, such as great durability, synergies with other adaptation measures etc.

***Possible measures***

- Greening, in particular:
  - Roof greening
  - Facade greening
  - Bucket-grown plants
- Shading, particularly by the use of:
  - Trees
  - Excess length of roofs
  - Awnings
- Expanse of water:
  - Fountain
- Reflectance of surfaces:
  - Light-coloured pavement

***Bundles of measures***

- Not applied in this case study

***Adaptation pathways***

- Not (yet) applied in this case study

#### 4.2.3 Step 3a: Selection of evaluation criteria

- Which positive and negative aspects should be considered in the evaluation of measures?
- Evaluation criteria should reflect all relevant positive effects (benefits) but also the negative effects (costs) measures could have.
- Already at this stage it is reasonable to define in which unit/ on which scale each criteria should be measured, i.e.
  - Monetary units
  - Other quantitative units
  - Qualitative statements, ordinal scale

***Potential benefit criteria***

Different benefit components can be:

- Avoided damages (at buildings, yields, insured persons, environment)
- Change of recreational function, tourism
- Change of potential for development
- Change of biodiversity and ecosystem services
- Change of values of goods or land
- Etc.

- All benefit criteria can be expressed in terms of:
  - Annual average damage avoided economic, environmental and social risks avoided); if benefit component spreads a lot between different years (large gap between implementation and effect of the measure): discounted value of benefits should be used (see annex 1 on cost-benefit analysis) or
  - Percentage of target achievement
  - Effectiveness in qualitative terms

***Potential cost criteria***

Different cost components can be:

- Investment costs
- Re-investment costs
- Running costs, operation and maintenance costs
- Transaction costs, i.e. costs associated with the design and implementation of measures, e.g. effort for participation and communication, negotiations, solving conflicts and other administrative costs (often not or not easily measurable in monetary terms)
- Other negative side-effects, such as negative environmental and social effects of the measures. I.e. building a dike reduces flood risk but could also have negative impacts on floodplain ecosystems.
- All monetary costs criteria can be aggregated to the net present value of costs (discounted value of costs, see annex 1 of this chapter on cost-benefit analysis)

***Potential further evaluation criteria:***

- Urgency:
  - Timescale: At what timescale does action need to be taken?
  - Time until measure becomes effective (time-lag between implementation and effect of the measure)
  - Lifetime of a measure (usually the measure with the longest lifetime determines the evaluation period)
- Benefits in the absence of climate change or climate variability (no regret, low regret and regret options)
- Synergies or conflicts with other measures
- Co-benefits in other areas, i.e. not determined as primary objective(s): economic, *(e.g. effect on employment),* environmental *(e.g. climate mitigation)*, social *(e.g. distributional impacts, quality of life)*
- Relevance of the measure: How important is the climate change threat addressed by the measure? (What economic values, ecosystem functions and socio-cultural values are at stake, and to what extent are they affected by climate change impacts? Is there an indication of overriding public interest, e.g. critical infrastructures, public health?)
- Windfall profit: Would or at which part would private stakeholders implement the measure autonomously?
- Dynamic incentive: Does the measure initiate further activities for adaptation to climate change?
- Acceptance: Is the measure accepted by the general public and/or key policy-makers (see also transaction costs)?
- Robustness: Is the measure effective under different climate scenarios and different socio-economic scenarios?
- Flexibility: Can the measure be adjusted according to changing conditions?

*Example, step 3a*

***Definition of evaluation criteria: costs and benefits***

Determination of appropriate evaluation criteria and categories of the characteristic attributes in agreement with local stakeholders

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**Measure:** ..............................

| **Description** | | | | | |
|---|---|---|---|---|---|
| .............................. | | | | | |
| **Criteria** | **Criteria values** | | | | |
| Lifetime | .............. years | | | | |
| | very high | high | moderate | low | very low |
| Technical effort | very low | low | moderate | high | very high |
| Time required for implementation | up to 1 month | up to 1 year | up to 5 years | more than 5 years | |
| Investment costs<br>Re-investment costs (100 years)<br>Running costs | .............. €<br>.............. €<br>.............. € p.a. | | | | |
| Cost bearer(s) | | | | | |
| Effectiveness regarding decrease of thermal load | very high | high | moderate | low | very low |
| Time span for measure to be effective | less than 1 year | up to 1 year | up to 5 years | up to 10 years | more than 10 years |
| Dependency of benefit on climate change | no-regret | low-regret | regret | | |
| Synergies with other measures | highly synergetic | synergetic | no synergies | | |
| Conflicts with other measures | non-conflicting | conflicting | highly conflicting | | |
| Co-benefits | high | moderate | low | no | |
| Assessment of feasibility by | | | | | |
| Local politicians | desired | no rejections | controversial | | |
| Citizens | desired | no rejections | controversial | | |
| Authorities | desired | no rejections | controversial | | |

**Figure 4-4: Evaluation form for individual measures**

- Present value of costs (considering a 3% p.a. discounting rate of investment and maintenance costs over a period of 100 years)
- Transaction costs: qualitative evaluation of planning and implementation efforts (including potential resistance of interest groups)
- Qualitative evaluation of the effectiveness of an individual measure for reducing heat stress, of the time until the effect takes place, and of likely synergies and conflicts with other adaptation measures

#### 4.2.4 Step 3b: Selection of evaluation method(s)

- The selection of an appropriate evaluation method(s) should be based on
    - Type of evaluation criteria
    - Data availability
- Accordingly, the following questions should be answered to find an appropriate approach:

- Is it possible to express all relevant cost and benefit criteria in monetary terms?
  - **Suggested method: Cost-benefit analysis** (see annex 4.1 for a detailed description)
    - Comparison of all monetary costs and benefits for each measure
    - The annual average damage avoided by the measure is usually the main benefit-related criteria.
    - Decision rule: the measure with the highest net present value (net present benefits minus net present costs) is selected.
- Is it possible to express the positive effect (objective) by a single non-monetary indicator?
  - **Suggested method: Cost-effectiveness analysis** (see annex 4.1)
    - Monetary costs are related to the percentage of target achievement (‘effectiveness’)
    - The method can only be used if measures for the same concrete target will be compared, like reduction of 1°K of heat stress in a house/neighbourhood, reduction of certain amount of substance concentration in water.
    - Decision rule: the measure is selected which achieves the target with lowest costs (or with the best relation of degree of target achievement to costs)
- Are there are several relevant objectives (or criteria), which include also criteria, which cannot be (or cannot be easily) expressed in monetary terms?
  - **Suggested method: Multi-criteria analysis** (see annex 4.1)
    - Aggregation of criteria with different units (EUR, cm, % etc.)
    - Multi-criteria analysis usually requires a weighting of criteria (see step 3c)
    - Decision rule: depending on the multi-criteria approach chosen (typical approaches are e.g. weighted sum approach, MAUT, Outranking approaches such as PROMETHEE

A brief guidance for each method can be found in Annex 4.1.

*Example, step 3b*

***Choice of evaluation method***

- No monetary damage estimates for heat stress available in the case of Jena ‚Eichplatz'
- A quantitative assessment of the effects of the adaptation options is only available for one of the measures (Predicted Mean Vote (PMV[8] differences for shading by the use of trees)).
    - ➢ No monetary assessment of the benefits of all considered measures possible
    - ➢ Assessment of the values of the qualitative criteria feasible by consultation of experts
- Consideration of multiple target values, therefore:
    - ➢ Application of a multi-criteria analysis (MCA)

### 4.2.5 Step 3c: Weighting of evaluation criteria

Only required for multi-criteria analysis

- Main question: Which weight should each of the criteria have in the final evaluation?
- Criteria weights should be determined by the decision makers and/or stakeholders
- Typical weighting procedures are:
    - „Swing-weight" - approach
    - „Point allocation" - approach
    - Pairwise comparison (AHP-approach)
    - Ordinal ranking
    - Importance scale
    - Importance-impact range graph

For brief guidance on the Swing-weight approach and the Point-allocation approach see annex 4.2.

***Weighting with several decision makers/stakeholder groups***

- If there are more than one decision maker/stakeholder/interest group the weighting procedure can be carried out for each of the different groups to obtain several different weighting sets which express the preferences of each group.
- By conducting the evaluation and prioritization (step 5) for each of these weighting sets the effect of the different preferences on the overall results can be shown.
    - ➢ This can be used as a starting point for discussion and search for compromise solutions.
- For approaches for participation of stakeholder or other actors in the evaluation process – see chapter 5 *Participation of citizens and stakeholders*.

[8] PMV values (Predicted Mean Vote) as indicators for heat comfort can be established with the help of microclimate modelling. The PMV values can be ascribed to heat or cold related stress levels.

*Example, step 3c*

***Weighting of criteria***

- Exemplary weighting for three stakeholder groups (based on point allocation procedure, see Annex 2)

**Table 4-1 Hypothetical weighting of evaluation criteria by stakeholders**

| | Criteria | Weights (%) | | |
|---|---|---|---|---|
| | | Stakeholder 1 Urban Planer | Stakeholder 2 Politicians | Stakeholder 3 Citizens |
| 1. | Costs | 60 | 60 | 35 |
| 1.1 | Net present costs | 45 | 60 | 40 |
| 1.2 | Technical effort | 15 | 5 | 10 |
| 1.3 | Time required for implementation | 10 | 10 | 15 |
| 1.4 | Assessment feasibility (politicians) | 5 | 10 | 10 |
| 1.5 | Assessment feasibility (citizens) | 5 | 10 | 20 |
| 1.6 | Assessment feasibility (authorities) | 20 | 5 | 5 |
| | *Sum* | *100* | *100* | *100* |
| 2. | Benefits | 40 | 40 | 65 |
| 2.1 | Effectiveness regarding decrease of thermal load | 40 | 45 | 50 |
| 2.2 | Time span for measure to be | 10 | 15 | 15 |
| 2.3 | Lifetime | 10 | 15 | 10 |
| 2.4 | Dependency of benefit on climate | 5 | 5 | 0 |
| 2.5 | Synergies with other measures | 10 | 5 | 5 |
| 2.6 | Conflicts with other measures | 10 | 5 | 0 |
| 2.7 | Co-benefits | 15 | 10 | 20 |
| | *Sum* | *100* | *100* | *100* |

### 4.2.6 Step 4: Data collection

- For each selected measure and each evaluation criterion used data needs to be collected, i.e. a decision matrix needs to be filled.
- An example how such a decision matrix could look like is shown in Figure 4-6 and Figure 4-7 (here the matrix is separated into cost and benefit criteria).

***Data sources***

- Data sources can be highly diverse, depending on the type of risk considered (heat, flood, health, water scarcity, etc), the evaluation criteria, type of measures etc.
- Potential sources could be:
  - Damage & impact assessment methods for different sectors
    - Link to WP3 models (health, flood, water scarcity, agriculture, ecological discharge)
    - Link to other existing models (LISFLOOD, etc.)
  - Existing studies on costs and benefits of measures (transferability?)
  - If no relevant data sources exist and own modelling cannot be carried out, expert consultations can be used to derive values for the performance of each alternative measure in each criterion.

***Time frame***

- Usually, the alternative measure with the longest lifetime determines the timeframe of the evaluation. E.g. if the lifetime of measure A is 75 years and the lifetime of measure B 25 years, the timeframe of evaluation is 75 years. For measure B re-investment costs after 25 and 50 years have to be considered then (or, in the dynamic pathways approach, a shift to another measure).

***Discounting of costs and benefits***

- After assessing all costs and benefits in monetary terms, they have to be discounted, i.e. converted into their present value in order to make them comparable (see Annex on cost-benefit analysis for detailed guidance).
- We recommend using the discount rate prescribed by national guidelines for climate change adaptation measures (or other public investments).
- In addition, to show sensitivity of results against different discount rates also a low and high discount rate should be tested (1% and 5%).

***Treatment of uncertainties***

Uncertainty with regard to impacts and their values is at the heart of any adaptation evaluation. Hence it cannot be treated as an additional issue and has to have a central role in the exercise. Ranges of possible values arise at several stages and form what is sometimes referred to as the uncertainty cascade. This starts with emission scenarios, global models and regional models. If we use the term in a broader climate change adaptation context we should also include uncertainties due to statistical downscaling, systems impacts and socio-economic impacts.

Further uncertainties result from the economic evaluation of costs and benefits:

- If cost or benefit assessments are based on transfers, i.e. transferring the estimates of one country/region from available data sources to other European countries/regions on the basis of some key indicators.
- If assumptions on the effect of a measure have to be included in the estimation. In the case studies such assumptions will be based on past examples and the evaluation of (local) experts and will be discussed with different actors. But if no concrete past examples exist uncertainty remain.

Figure 4-5 summarizes the different stages at which data might be uncertain.

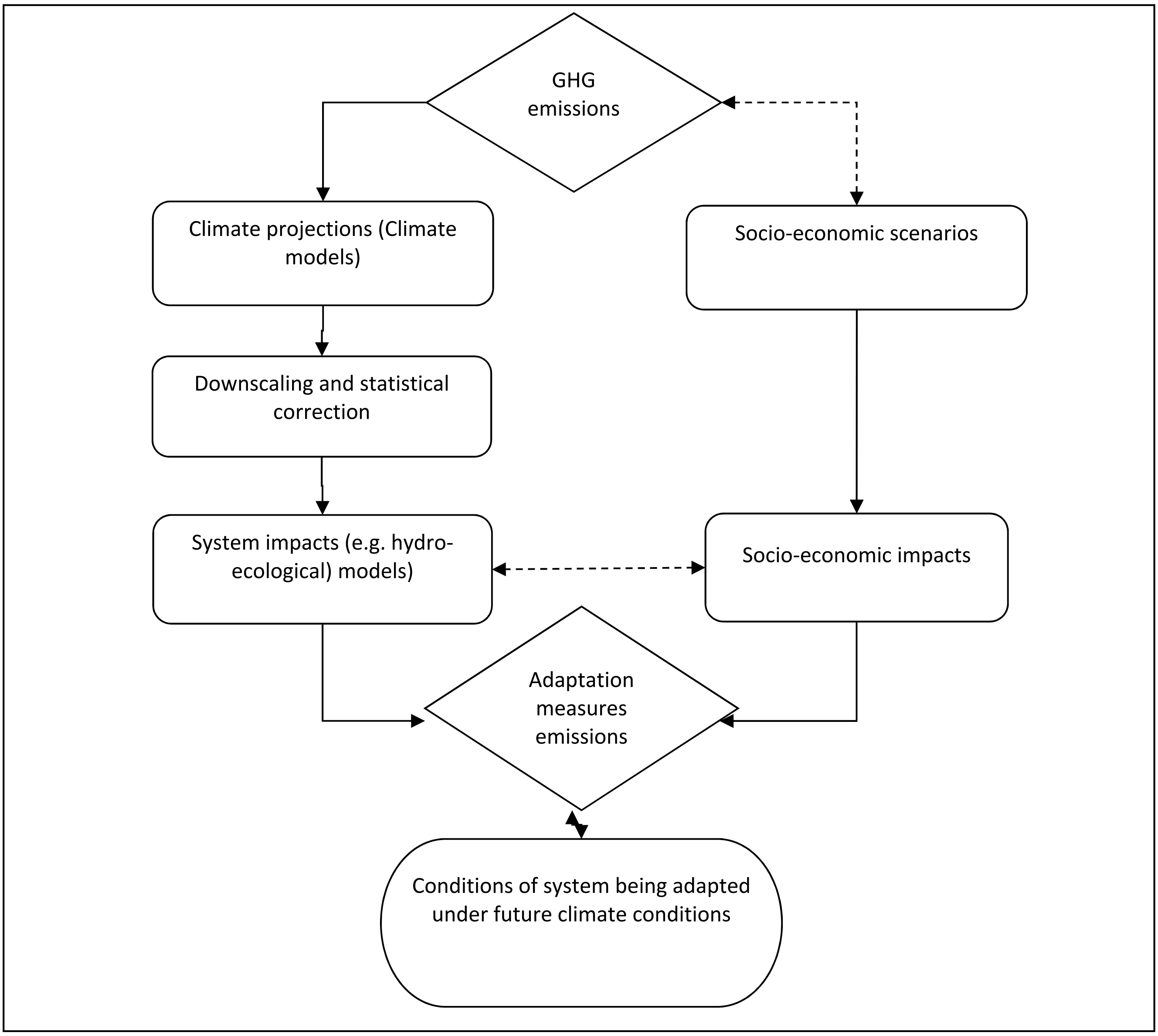


**Figure 4-5: Structural elements in the assessment of climate change impacts and adaptation illustrating the uncertainty cascade**

Once the data has been collected it is important to provide the full set to the decision maker. This means that the whole range of values should be made available, not just the average. Furthermore, it is useful to indicate what is better determined and what is less well determined, e.g. do we have a narrower range for temperature or for precipitation?

Once the uncertainty has been properly represented the cascade results in a range of values for the main impacts and possibly in a range of values for the costs of the adaptation measures. The commonest way to handle such ranges at the evaluation stage is to use the mean values (averages). While this is useful it is not enough for choosing the option. The decision-makers need some idea of the uncertainty, which can be represented through a sensitivity analysis. When carrying out the evaluation using economic criteria such as cost benefit analysis or cost effectiveness analysis the sensitivity can take the form of simple calculations of lower and upper bounds based no plausible bounds for the different components of the uncertainty cascade; alternatively it can take the form of a Monte Carlo analysis where ranges for the different elements in the cost and benefit calculation are fed into a model that calculates the implied net benefits or other measure of performance for each option under consideration. Indeed software tools such as 'Tornado' or 'Crystal Ball' are commercially available to carry out the sensitivity analysis and supporting Monte Carlo exercises.

A project document that does not report the sensitivity of the outcome indicator (e.g. the internal rate of return or net present value) to key parameters such as the costs or other uncertainties would be considered a poor piece of work. Likewise the analysis would be expected to identify the robustness of the chosen option to the dominant uncertainties.

An alternative to handle uncertainty within the framework of a cost benefit or cost effectiveness analysis as described above is to use decision-making tools in which the uncertainty has a central role but which do not involve calculating expected values or averages. A description of rules that have been developed for this purpose is given in Table 4-2.

**Table 4-2: Options to account for uncertainties in decision processes**

| Method | Decision Criteria | Assumptions | Comments |
|---|---|---|---|
| Maximin | Each option has a range of outcomes, one for each scenario. The score for each option is the minimum outcome value and the selected option is the one with the highest score. | This is an extreme risk aversion approach. In our example we would always build a sea wall as long as the cost is less than the maximum damage. | Such extreme risk aversion rarely reflects social preferences. It has the advantage that the outcomes need not be quantified on a cardinal scale. |
| Minimax Regret | For each scenario subtract the outcome of the option that does best in that scenario from the outcomes of other options in that scenario. This gives a regret table. For each option calculate the maximum regret and select the options with the smallest of these. | Rule is applicable when we care about missed opportunities. Generally less pessimistic than Maximin. | Ranking between two options can change if a third option is introduced. Does require outcomes to be quantified on a cardinal scale. |
| Info-gap Decision Theory for Robustness | Construct a measure of the maximum amount of uncertainty we are exposed to and still ensure that losses do not exceed a given level. The decision maker then specifies an acceptable level of loss and chooses an option that has the lowest uncertainty subject to that loss limit. | Not a formal decision making process and can be expanded to include gains from different options as well (referred to a opportuneness). | Very much an *ad hoc* decision rule, but one that recognizes the limits of simple robustness approaches. |
| Multi-criteria Analysis (MCA) | Each option is scored against a number of criteria and the option with the highest score is chosen. One of the criteria could be the robustness of outcomes in the face of uncertainty. | Agreement can be reached on the weight to be given to each criterion. This may be difficult. | Some sensitivity of the chosen option to different weights or scoring methods is normally required. |

Of the four methods described in the table the one that has most attraction within the BASE community is probably multi-criteria analysis (MCA). One possibility to include the uncertainty dimension in MCA is to add a separate uncertainty criteria, with its own weighting. In the PRIMATE decision support tool it is possibly to directly consider the uncertainties of the alternatives' performance for each criterion (e.g. as a range, a triangular distribution or any other probability distribution). PRIMATE then takes these uncertainties via Monte-Carlo-simulation into account for the ranking of options. I.e. if PRIMATE is used it is not necessary to add a separate uncertainty criterion.

- Following aspects should be documented:
  - Uncertainties in the data:
    - At least use of uncertainty margins (e.g. „300-450 EUR“).
    - If possible also information on the distribution function.
  - What is the performance of the measure in the best/the worst case?
  - Different types of uncertainties in the input data can be included in the PRIMATE evaluation tool (margins, triangular distributions, other distribution functions)
  - Is there no data at all available for a certain evaluation criteria?
  - If necessary, refine the criteria catalogue (back to step 3)

*Example, step 4*

***Data collection***

- Assessment of data availability and identification of relevant contact persons jointly with the responsible parties of the city planning department

| Measure | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Cost-related criteria | | | | | | |
| | | **Investment costs/ Re-investment costs** in € | **Running costs** in € p.a. | **Technical effort** 1 = very low 2 = low 3 = moderate 4 = high 5 = very high | **Time required for implementation** 1 = up to 1 month 2 = up to 1 year 3 = up to 5 years 4 = more than 5 years | **Assessment of feasibility by local politicians** 1 = desired 2 = no rejections 3 = controversial | **Assessment of feasibility by citizens** 1 = desired 2 = no rejections 3 = controversial | **Assessment of feasibility by authorities** 1 = desired 2 = no rejections 3 = controversial |
| **No.** | **Denomination** | | | | | | | |
| 1.1 | Expanse of water: Fountain | | | | | | | |
| 2.1 | Greening: Bucket-grown plants | | | | | | | |
| 2.2 | Greening: Roof greening | | | | | | | |
| 2.3 | Greening: Facade greening | | | | | | | |
| 3.1 | Shading: Excess length of roofs | | | | | | | |
| 3.2 | Shading: Awning | | | | | | | |
| 3.3 | Shading: Trees | | | | | | | |
| 4.1 | Reflectance of surfaces: Light-coloured pavement | | | | | | | |

**Figure 4-6: Data matrix of alternative measures and cost criteria**

| Measure | | Benefit-related criteria | | | | | | |
|---|---|---|---|---|---|---|---|---|
| No. | Denomination | Effectiveness regarding decrease of thermal load<br>1 = very high<br>2 = high<br>3 = moderate<br>4 = low<br>5 = very low | Time span for measure to be effective<br>1 = less than 1 year<br>2 = up to 1 year<br>3 = up to 5 years<br>4 = up to 10 years<br>5 = more than 10 years | Lifetime<br>1= very high<br>2 = high<br>3 = moderate<br>4 = low<br>5 = very low | Dependency of benefit on climate change<br>1 = no-regret<br>2 = low-regret<br>3 = regret | Synergies with other measures<br>1 = highly synergetic<br>2 = synergetic<br>3 = no synergies | Conflicts with other measures<br>1 = non-conflicting<br>2 = conflicting<br>3 = highly conflicting | Co-benefits<br>1 = high<br>2 = moderate<br>3 = low<br>4 = no |
| 1.1 | Expanse of water: Fountain | | | | | | | |
| 2.1 | Greening: Bucket-grown plants | | | | | | | |
| 2.2 | Greening: Roof greening | | | | | | | |
| 2.3 | Greening: Facade greening | | | | | | | |
| 3.1 | Shading: Excess length of roofs | | | | | | | |
| 3.2 | Shading: Awning | | | | | | | |
| 3.3 | Shading: Trees | | | | | | | |
| 4.1 | Reflectance of surfaces: Light-coloured pavement | | | | | | | |

**Figure 4-7: Data matrix of alternative measures and benefit criteria**

***Data sources***

- Expert interviews (urban planner, architects, landscape architects, business enterprises, communal service provider)
- Relevant scientific studies etc.

***Strategies in dealing with uncertain data***

- Collection of maintenance costs based on cost calculations for similar projects.
- Utilization of ranges for monetary and qualitative data.
- Qualitative estimation of transaction costs.

#### 4.2.7 Step 5a: Conducting the evaluation with the selected evaluation method

For the evaluation different evaluation methods exist (see step 3):

- See brief guidance of evaluation methods (CBA, CEA and MCA) in Annex 4.1.
- Evaluation software can be used to support the evaluation process. Available software tools which support CBA and/or MCA include Definite[9], D-Sight[10], SALDO[11], CLIMACT Prio[12], HIPRE 3+[13], ADx[14] and PRIMATE[15]

***Example: PRIMATE (can be used for CBA and/or MCA)***

- Fill in the decision matrix:
  - Alternative measures (rows)
  - Evaluation criteria (columns).
  - Determine if criteria should be minimised or maximised.
  - Define uncertainties for each criterion
  - Define indifference and preference thresholds for each criteria
- Fill in data from step 4.
- Determine criteria weights (see step 3).
- Run the evaluation.
- A detailed description of the tool is provided in the PRIMATE handbook

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[9] Provides MCA and CBA; http://www.ivm.vu.nl/en/projects/Projects/spatial-analysis/DEFINITE/index.asp
[10] Provides MCA with the PROMETHEE approach; http://www.d-sight.com/
[11] Provides MCA for climate adaptation options with fixed criteria; www.austroclim.at/fileadmin/user_upload/StartClim2010_reports/StCl10_C_bewertungstool_FINALSchutz.xls
[12] Provides MCA for climate mitigation and/or adaptation options; http://www.ihs.nl/research/research_projects/climact_prio_tool/
[13] Provides MCA with the Analytic Hierarchy Process (AHP) and Simple Multi-attribute Rating Technique (SMART); http://sal.aalto.fi/en/resources/downloadables/hipre3
[14] Provides MCA; http://weadapt.org/knowledge-base/adaptation-decision-making/adaptation-decision-explorer
[15] Drechsler, M., Lange, M., Meyer,V. (2009): PRIMATE - An interactive software for Probabilistic Multi-Attribute Evaluation, Software handbook, Leipzig.

*Example, step 5a*

***Implementation of the Evaluation (Multi-criteria Analysis)***

- Data were, as described above, analysed with PRIMATE

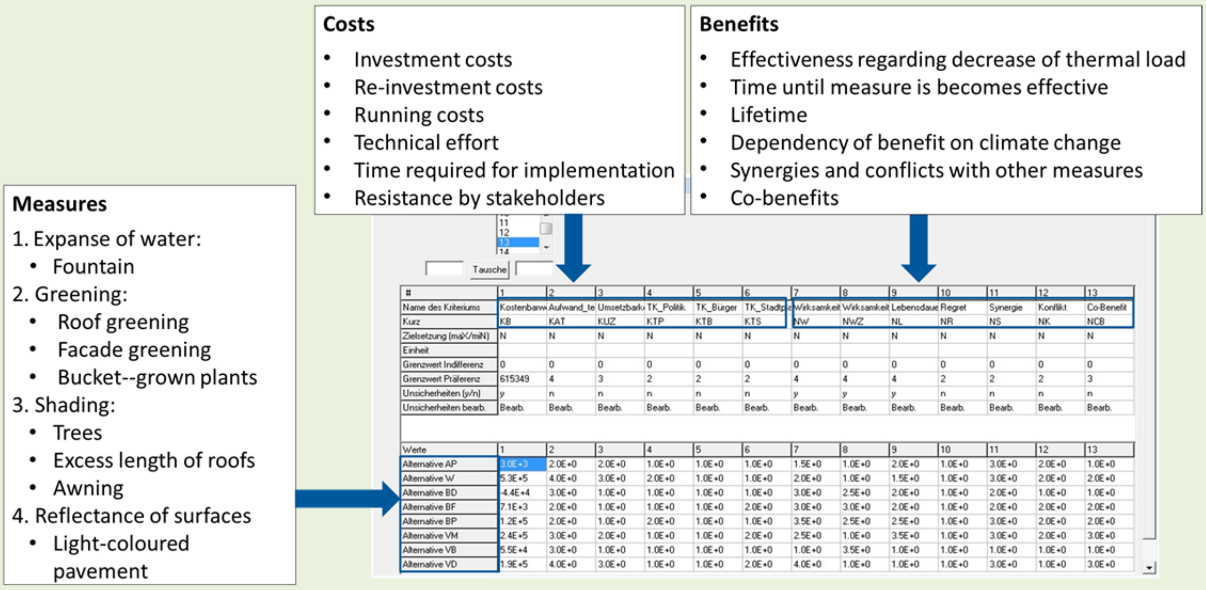



**Figure 4-8: Completed PRIMATE data sheet**

- Inserting weights for individual criteria and groups of criteria (costs and benefits) in correspondence with Table 4-1.

Starting of the evaluation in PRIMATE.

### 4.2.8 Step 5b: Presentation of results

- The different evaluation methods (see step 3 and Annex 4.1) lead to different outputs, i.e.
  - CBA: net present value and/or benefit-cost ratio
  - CEA: costs required for target achievement or effectiveness-cost ratio
  - MCA: depending on the method
    - PROMETHEE: net fluxes
    - Weighted sum, MAUT: normalized values (0-1)
- Depending on the decision rule of each method, a ranking of the measures can be derived.

***Communication of uncertainties*[16]**

- PRIMATE considers the uncertainties in the input values (as well as in the criteria weights) and therefore creates a ranking probability (see Figure 4-9).
- For net present values or cost-benefit ratios: average values or ratios should be accompanied by the variability of the ratio (min/max-ratios), e.g. benefit-cost-ratio for a measure is: average: 0.16, variability: 0.10-0.20.
- Remaining uncertainties in the results of the evaluation process have to be made transparent.
- Are the uncertainties in the results too high to come to a decision?
    - Try to improve the data basis (back to step 4).

*Example, step 5b*

***Evaluation results***

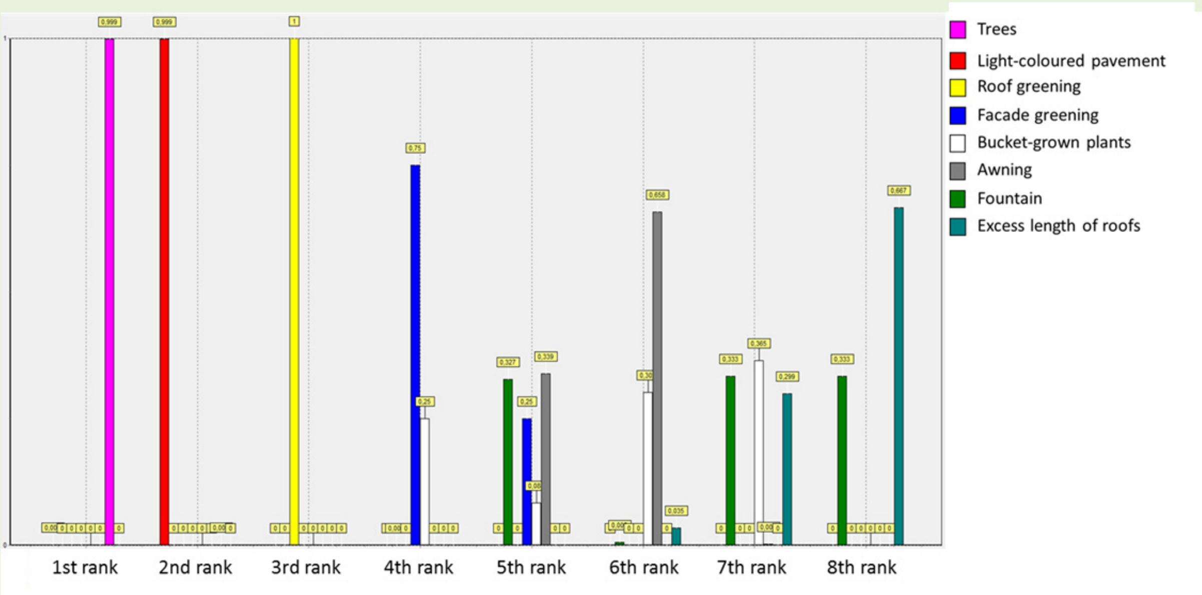



**Figure 4-9: Ranking of evaluated measures**
Note: Numbers indicate the probability that is assigned to the concerning rank.

Results based on the hypothetical weighting:

1. Shading by the use of trees
2. Use of light-coloured pavement
3. Roof greening

The results show the probability being very high that the measures

- … tree planting, use of light-coloured pavement, roof greening (and facade greening) are most appropriate to reduce heat stress efficiently.
- … compartmentalised greening with bucket-grown plants, installation of awnings, excess length of roofs and a fountain are less efficient in reducing heat stress in comparison with the aforementioned measures.

[16] Please also see http://infobase.circle-era.eu/ for links to different adaptation projects dealing with uncertainties.

## 4.3 Example: Restoration of pasture land

### 4.3.1 Short introduction

- Example is based on Tröltzsch et al., 2012
- Analysis of a concrete case at the river Elbe in the north of Germany (size of restoration area: 611 ha, potential 13 m $m^2$ water retention)
- Sector: biodiversity, water (flood protection)
- Urgency: high, because long implementation time and time-lag between implementation and effect

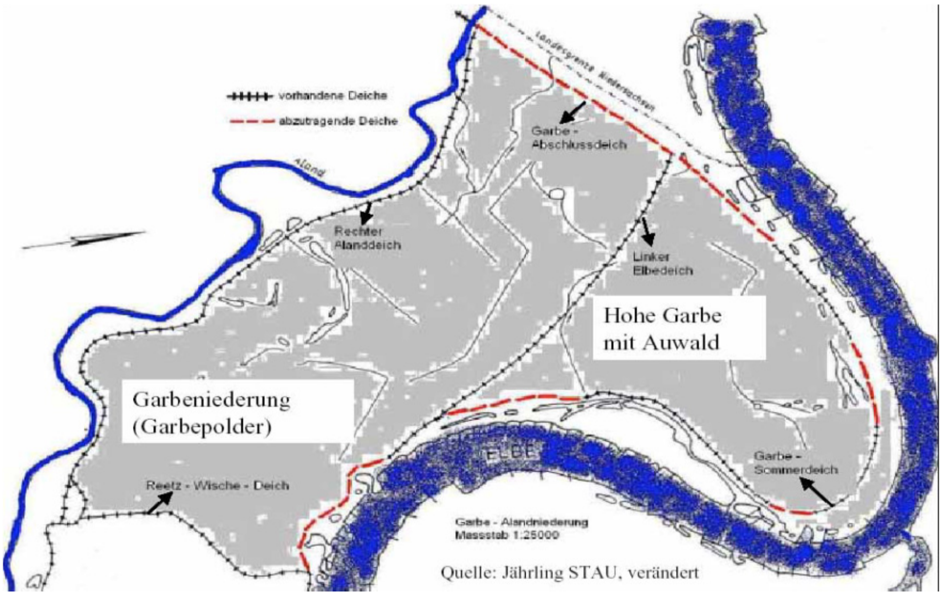



**Figure 4-10 Area for restoration of pasture land.**

- Measure: Area is splitted: 1. Area of Hohe Garbe is already indicated as floodplain and protected by a summer dike. There partially pasture land exist. 2. Garbeniederung is behind the Elbe dike and used as agricultural land. For the adaptation measure it is needed to rebuilt the existing dike, e.g. with 4 slots (red) Building of new dike as Elbe winter dike (Western and Southern part). Further floodplains for Elbe: 611 ha, retention of 13 m $m^3$ of water is possible in case of Elbe floods. The measure would be part of a biotope network.
- Objective: Economic analysis of one measure compared to the baseline option (business as usual): restoration of pasture land in this area.

### 4.3.2 Step 1: Preliminary risk assessment

- For Germany in general and also the river Elbe an increased probability of flood events is expected. In this region climate scenarios propose a precipitation increase in winter of maximum 38% in 2071-2100 compared to 1961-1990. (COSMO-CLM, REMO, RCAO: Regionaler Klimaatlas Deutschland).
- Different large flood events already occurred in the last years, e.g. 2002, 2013.
- No own risk assessment for the area was conducted. But different studies for similar restoration projects neighbouring the case study area exist. These studies show a flood reduction between 9 and 40 cm for a restoration area of 400 ha. Furthermore effects for cities nearby are expected, e.g. Wittenberge.
- Timeframe: The estimation was prepared for 90 years (2011-2100).

### 4.3.3 Step 2: Identification of adaptation measures

- Primary objectives: Decrease the flood damages in the region and protect biodiversity, especially because the measure is part of a biotope network.
- Further objectives: Increase of landscape and recreational value

***Possible measures***

- Only one measure discussed (see above).

***Adaptation pathways***

- No possibility to apply in the study.

### 4.3.4 Step 3a: Definition of evaluation criteria: costs and benefits

Evaluation criteria according to criteria set, which was developed in the project:

**Table 4-3 Evaluation criteria for assessing measures for restoration of pasture land**

| Basic information | Cost/benefit | Evaluation |
|---|---|---|
| Sector | Costs: direct costs, further economic costs, external costs | Relevance |
| Type of measure | Benefits: economic, environmental, socio-economic benefits | Effectiveness |
| Relevance for public sector | Uncertainty of evaluated costs and benefits | Windfall profits |
| Urgency, Time-lag between implementation and effect, life-time | | Dynamic incentives |
| | | Acceptance |
| | | Interactions with other adaptation measures |
| | | Flexibility (no-regret, scenario-variability) |

- Present value of costs and benefits (considering a 1.5% p.a. discounting rate over a period of 90 years)
- Qualitative evaluation of further criteria (basic criteria: descriptive; uncertainty, costs/benefits evaluation critera: high, medium, low)

#### 4.3.5 Step 3b: Choice of evaluation method

- Objective was to monetise as many cost and benefit components as possible.
- Further criteria evaluated in qualitative terms.
- Therefore: cost-benefit analysis (for additional criteria also multi-criteria analysis).

#### 4.3.6 Step 3c: Weighting of criteria

- Not applied in the case study.

#### 4.3.7 Step 4: Data collection

- Based on desktop research and interviews.

***Data sources***

- Information on local case study area
- Studies on pasture land restoration and regional models/calculations of effects on flooding events
- Cost data for restoration of pasture land and further benefits (mainly from regional studies)

***Strategies in dealing with uncertain data***

- Use of ranges for monetary data and also necessary assumptions are partially done as ranges,
- Comparison of total costs with data estimated by a local planning company

***Implementation of the Evaluation***

- All cost and benefit components were included in an Excel-sheet, which was also used for discounting the different components.
- Included cost components:
    - Costs to rebuilt dikes and built new dikes
    - Costs to buy land from farmers
    - Lost income of farmers
    - Planting costs for pasture forest
- Included benefit components:
    - Lower maintenance costs for dikes, due to shorter length
    - Avoided damage costs in case of flood event
    - Nutrition retention
    - Evaluation of biodiversity
- Further evaluation qualitative criteria were estimated

### 4.3.8 Step 5: Evaluation results

**Table 4-4: Evaluation results: Costs, benefits, Benefit-cost ratio***

| | Current situation (assuming no climate change) | With climate change | Main factors |
|---|---|---|---|
| Costs | 10 m EUR | 10 m EUR | Dike re/building, income losses |
| Benefits | 20-35 m EUR | 30-45 m EUR | Value for biodiversity conservation |
| Net present value (NPV) | 10-25 m EUR | 20-35 m EUR | |
| Benefit-cost ratio | 2 - 3.4 | 3 - 4.5 | |
| Uncertainty of estimation | High | | |

Note: Discounted costs and benefits until 2100.

**Table 4-5: Evaluation results: Qualitative criteria**

| Criteria | Evaluation | Further description |
|---|---|---|
| Relevance | Need-to-have | Because biodiversity conservation is basis for human livelihood |
| Effectiveness | High | Restoration would increase adaptive capacity of eco-systems, effect is proofed. |
| Windfall profits | No | Because nature conservation mainly task of public institutions |
| Dynamic incentive | Yes | Incentive for nature-oriented flood protection. |

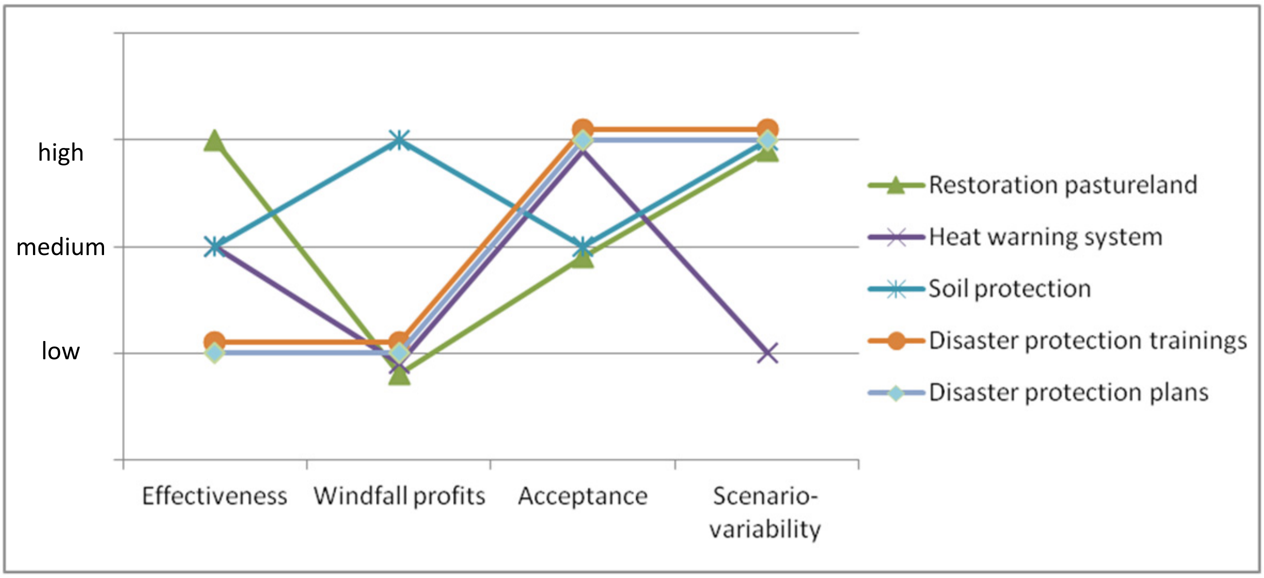



**Figure 4-11: Evaluation results: Comparison of different measures**

## 4.4 Conclusions

As the two different case study examples show the stepwise procedure described in this section can be applied under different context conditions (risks, impacted sectors, data availability, etc.). Depending on the type of evaluation criteria used and data available for analysis different evaluation approaches might be applicable, such as cost-benefit analysis, cost effectiveness analysis and/or multi-criteria analysis.

Furthermore, possibilities to handle uncertainties in the input data in the evaluation process are presented. The decision support tool PRIMATE or alternative tools can support for the various types of economic assessments described above and to include uncertainties in the outcomes of the evaluation process.

## 4.5 Annex

### 4.5.1 Brief guidance for alternative evaluation approaches

***Cost-benefit analysis***[17]

Project definition

- Selection of alternative option (measures),
- Determination of the evaluation timeframe

Quantification and monetisation of all relevant project impacts

In principle, all costs and benefits of the alternative options have to be included in monetary terms. These should be estimated for each year of the evaluation timeframe for every single measure (compared to the reference measure = the business as usual or do-nothing option).

Typically, investment costs occur in year 0 of the evaluation timeframe, while current costs have to be accounted for each year, and potentially re-investment costs may be necessary after a certain amount of time.

Benefits of climate adaptation measures are usually estimated with the reduction of expected annual damage. Such annual expected damage can be estimated in quantitative terms usually only based on modelling. Where such modelling is not available in terms of existing studies or own modelling resources, only proxies can be identified in close cooperation with stakeholders that can function as an indication for the measures' benefits. In addition, this annual expected damage value and thus the benefit of an alternative measure within the evaluation timeframe is subject to change to due climate change and other socio-economic changes.

Discounting

After assessing all costs and benefits in monetary terms they have to be discounted, i.e. converted into their present value in order to make them comparable. The rationale for this is *time preference* of people: benefits as well as cost are valued higher the sooner they are received or have to be paid, respectively (Hanley and Spash 1993).

In order to discount future values to their present value a discount rate is used:

$$PV(X_t) = X_t\left[(1+i)^{-t}\right]$$

With $PV(X_t)$ : present value of $X_t$

$X_t$: cost or benefit received in time t

i: discount rate

Obviously, the choice of the discount rate has a huge influence on the weight given to future costs and benefits: a high discount rate would mean to give only small weight to cost and benefits which occur in the future, whereas a low discount rate gives them a higher weight. There is an on-going debate about a "right" social discount rate, but different authors argue against a straight line discount rate (see e.g. Gowdy 2007, Turner et al. 2007) and recommend a declining discount rate. The rationale is that people discount the near future at a higher rate than the distant future. Furthermore, the position of future generations in strengthen by such declining discount rates as future costs and benefits get more influence on the net present value. E.g. the official German methodological

[17] See Hanley and Spash (1993), Pearce and Turner (1990).

guideline for the valuation of environmental damage uses such a declining discount rate by recommending a discount rate of 3% for a timeframe of up to 20 years and a discount rate of 1.5% for impacts occurring after that.[18]

It is recommended to use the discount rate prescribed by national guidelines for climate change adaptation measures (or other public investments). In addition, also a low and high discount rate should be tested to show sensitivity of results against different discount rates (e.g. 1% and 5%).

Decision rules

The usual criterion for the evaluation of projects in a cost-benefit framework is the *Net Present Value test*. The Net present Value (NPV) is defined as the sum of discounted benefits minus the sum of discounted costs over the lifetime of a project (Hanley and Spash 1993):

$$NPV = \sum_{t=0}^{n} B_t (1+i)^{-t} - \sum_{t=0}^{n} C_t (1+i)^{-t}$$

The first test would be to check if the NPV of a project is positive, i.e. if its benefits exceed its costs. If yes, it could be stated that this project would lead to a gain in social welfare and should be accepted.

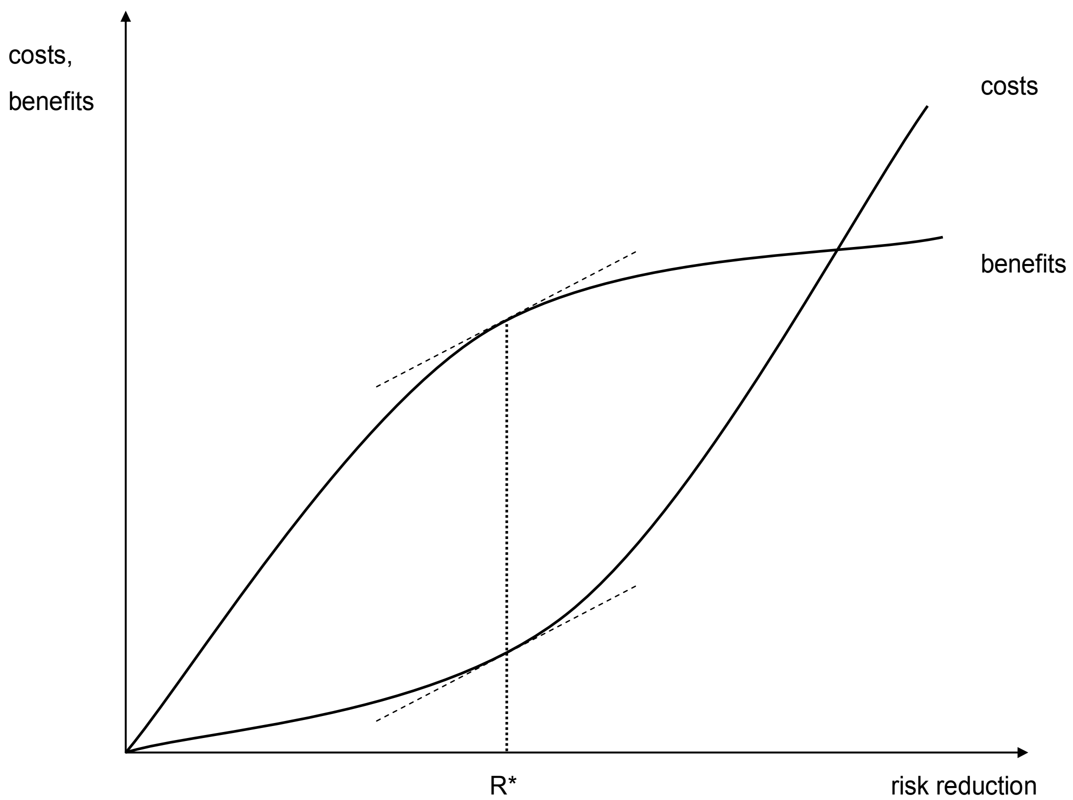



**Figure 4-12: The Pareto optimum of risk reduction**
Source: Young (2005), Weck-Hannemann and Thöni (2006)

However, if there is more than one alternative the second decision rule can be applied, i.e. to choose the project with the highest NPV. Ideally the NPV should be maximized in order to meet the Pareto optimum defined at the beginning of this chapter. Generally, it is assumed that with an increasing level of investments in risk reduction,

[18] In contrast, MAFF (1999) prescribe a constant discount rate of 6% for flood alleviation projects. On the other side, the *Stern report*, estimating the economic impacts of climate change, describes discounting as unethical with regard to future generations and applies a discount rate of 0.1% (Stern 2006).

benefits increase with a decreasing rate while costs increase with an increasing rate (Young 2005, Weck-Hannemann and Thöni 2006, see Figure 4-12).[19] If this is the case, the Pareto optimal level of risk reduction (R*) would be at the point where marginal benefits equal marginal costs (ebd.).

However, like Young (2005) states, CBA in practice is typically not seeking for that optimum solution. Instead, among a set of options the alternative is chosen which comes nearest to the Pareto efficiency. This is true also for the practice of planning flood risk management projects where it would be quite difficult to calculate marginal costs and benefits for all of the variety of different options. Accordingly, the project with the highest NPV should be selected.

An alternative cost-benefit criterion is the benefit-cost ratio (BCR), which is the ratio of discounted benefits to discounted costs:

$$BCR = \frac{\sum_{t=0}^{n} B_t (1+i)^{-t}}{\sum_{t=0}^{n} C_t (1+i)^{-t}}$$

A BCR > 1 indicate a positive impact of the project on social welfare, like an NPV > 0 does. But in contrast to the NPV the BCR does not measure the total impact of the project on social welfare but the relation of its benefits to its costs. E.g., assuming a run of the benefit and cost curve as shown in Figure 4-12 the BCR would be highest for relatively small projects, which have on the other side only a relatively little NPV. Hence, the ranking of alternatives would be different when using the BCR instead of the NPV criterion.

The choice whether the NPV or the BCR should be used depends on the decision situation: If e.g. one project should be chosen among a set of options then the decision rule would be to choose the one with the highest NPV. If, on the other side, capital budget is fixed and several projects should be carried out with this budget the right decision rule would be rank the projects by their BCR and accept them in order of their ranking until the budget is exhausted (Pearce and Smale 2005).

Sensitivity analysis

Sensitivity analyses should be carried out to identify whether variations in the input data (e.g. discount rate) used lead to implications for the final results.

***Cost-effectiveness analysis***[20]

1. *Definition of alternative options or measures, and evaluation timeframes*

Alternative options or measures are to be identified and an evaluation timeframe should be determined. All costs of alternative measures can be assessed in terms of monetary units.

2. *Define a non-monetary target indicator*

Stakeholders define a non-monetary indicator for the different utilities of the alternative measures (here effectiveness of a measure can include, for instance, reduction of heat stress, the protection against and up to a 100year flood event, etc.). Such an indicator can be either quantitative (e.g. protection of specific number of people) or qualitative (e.g. low, medium or high protection).

3. *Quantify cost and effectiveness of the different options within the evaluation timeframe*

In the same manner as for the CBA, determine the present value of alternative measures and assess the effectiveness regarding the aforementioned target indicator of each individual measure.

[19] Admittedly, empirical evidence from the UK showed that for the national level costs of flood protection could also increase with an even higher declining rate than the benefits (Pearce und Smale 2005). In this case the NPV of flood protection projects increases the more is invested.
[20] See e.g. Hanusch (1994).

4. *Decision rules*
   - Costs to achieve the defined target
     - If a defined target that should be achieved (e.g. the protection against and up to a 100 year flood event, or the attainment of good ecological conditions) had been established, the alternative measure is chosen that achieves this objective at the lowest cost.
   - Effectiveness at a given cost level
     - If in turn, the cost for the measure is predetermined, that measure is chosen which is the most effective in reaching the determined target.
   - Ratio of effectiveness and costs
     - In the case of a fixed budget and non-precluding measures, those measures with the highest cost-effectiveness ratio will be selected until the budget is exhausted.
5. *Sensitivity analysis*

   Sensitivity analyses should be carried out to identify whether variations in the input data used (e.g. discount rate) lead to implications for the final results.

***Multi-criteria analysis***

Lots of different MCA-methods exist (see e.g. Zimmermann and Gutsche (1991) an overview (Weighted sum, MAUT, AHP, PROMETHEE, ELECTRE, …).

In the PRIMATE tool the PROMETHEE approach us used. PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluations) performs a pairwise comparison of all alternatives across all evaluation criteria counting arguments “in favour” and “against” each option. Uncertainties in the criterion values can be considered by using a Monte Carlo simulation approach (Stochastic PROMETHEE II), i.e. several PROMETHEE analyses are performed for a random sample of criterion values within a range to be defined.

A detailed description of the Stochastic PROMETHEE approach is given in the PRIMATE handbook.

#### 4.5.2 Brief guidance weighting procedures

***‘Swing-Weight’-approach***

The swing weight approach is a trade-off analysis method, which considers the range of each criterion. It is a relatively easy to apply approach which involves three steps (Malczewski 1999, RPA 2004):

1. *Ranking:*

The starting point is a hypothetical alternative with all criteria at their lowest level. The decision maker is asked which criteria he would most prefer to have a swing to its highest level – the criteria would be ranked first, the next one second and so on.

2. *Relative importance:*

The criterion ranked first is given a score of 100. The decision maker is asked now about the relative importance of a swing from lowest to highest level in the criterion ranked second compared to a swing in the first one (e.g. 50%). Then the criterion ranked third is compared to the first one (e.g. 10%) and so on.

*3. Standardisation:*

Finally, the scores gathered in 2) are standardised by the sum of all scores:

$$w_1 = \frac{100}{100 + 50 + 10} = 0.625$$

$$w_2 = \frac{50}{100 + 50 + 10} = 0.313$$

$$w_3 = \frac{10}{100 + 50 + 10} = 0.063$$

When making a choice of a weighting procedure, a trade-off between ease of application and accuracy has to be made: Rating and especially ranking require little effort but do not have a theoretical foundation, which can lead to inaccurate weights. The swing weight and the pairwise comparison may lead to more precise results but require more effort (Malczewski 1999).

***Point allocation approach***

The *point allocation approach* seems to be the approach simplest to apply. Here the decision maker is asked to allocate 100 points among the selected criteria. The rationale of this approach is that the decision situation is quite similar to the financial allocation of a given budget and therefore quite familiar to many decision makers. Nevertheless, (Malczewski 1999) mentions the risk within this approach that the criteria are weighted without knowing their specific unit and range. In this case the weights would be meaningless.

***Other approaches:***

- Ordinal ranking
- Pairwise comparison (from AHP)
- Importance Scale
- Importance-impact range graph

#### 4.5.3 Step-by-step summary of guidance

**Table 4-6: Step-by-step summary of guidance**

| General and specific steps | Approach |
|---|---|
| **Step 1 Preliminary risk assessment** | |
| Determine existing problems | Analysis of past events |
| Assess current risk situation | Refer to existing risk or vulnerability studies |
| Assess assets at risk | Asset mapping (land, buildings, infrastructures, natural capital, and social capital) based on desktop research and expert interviews. Identify sector(s) and key assets, timeframe |
| Determine existing adaptation measures | |
| Expected changes in risk due to climate change and socio-economic change (areas, sectors and assets) | For ex-post case studies: describe climate scenarios and socio-economic change scenarios used, as well as expected impacts on which affected areas and sectors. |
| | For on-going and prospective case studies: use new scenarios for climate and socio-economic change from IPCC AR5 downscaled and adjusted to local economy PPC. |
| | Refer to existing studies on climate change impacts and vulnerabilities. |
| | If unavailable, carry out own modelling if resources are sufficiently available. |
| | Expert interviews on expected climate change impacts on assets at risk, as well as plans and ideas for assets in future. |
| **Step 2 Identification of adaptation measures and adaptation pathways** | |
| Identify primary and other potential objectives of adaptation | |
| Determine potential measures to attain primary or other objectives | In close cooperation with stakeholders selection of potential measures which:<br>• Fulfil the objective(s) on different timeframes,<br>• Already exist but could also benefit adaptation objective(s),<br>• May provide benefits independent of the occurrence of climate change,<br>• Provide co-benefits<br>Detailed description and possibly displaying measures based on mapping activities. |
| Define baseline option | Determine baseline upon which all costs and benefits are compared to. If you take a business as usual approach, current protection levels are assumed for the evaluation timeframe. |
| Bundling of measures | Identify complementary measures to attain the objective(s). |
| Adaptation pathways | Identify threshold and adaptation tipping points, including their timing as well as to which objective(s) they relate to. |
| | Identify courses of actions |

| | |
|---|---|
| **Step 3a Selection of evaluation criteria** | |
| Identify appropriate evaluation criteria | Determine evaluation criteria that reflect all relevant positive (benefits) and negative (costs) effects, and suitable categories of criteria values consulting relevant stakeholders. |
| | Define appropriate units to measure criteria. |
| **Step 3b Selection of evaluation method(s)** | |
| Identification of appropriate method(s) | Select appropriate method(s) based on type of criteria and data availability (method overview in annex 1). |
| **Step 3c Weighting of evaluation criteria** | (Applicable only to MCA) |
| Identify evaluation weighting method | Choose swing- weight or 100- point allocation method (see overview in annex 1). |
| Attach weights to the evaluation criteria (potentially in different groups) | According to method chosen, attach weights with stakeholders. In the case of multiple stakeholder or interest groups, a number of weighting sets can be obtained. These then steps 5 and 6 can be evaluated and prioritized, illustrating the effects on the overall results depending on weighting set chosen. |
| **Step 4 Data collection** | |
| Data sources for data collection for each criteria selected | Identify potential data sources, including damage & impact assessment methods (link to WP3 and other existing models) or existing CBA studies on adaptation measures. |
| | If no relevant data sources are available and modelling cannot be undertaken, identify in cooperation with experts proxies for assessing the performance of measures regarding the respective criterion. |
| Evaluation timeframe | Commonly determined by the measure with longest lifespan. For measures with shorter lifespans then either re-investment costs need to be considered or, in the dynamic approach, shifts to other adaptation measures. |
| Discounting of costs and benefits | Suggested use of discount rate determined by national guidelines for climate change adaptation measures (or public investments). |
| | Application of low and high discount rates in the sensitivity analysis. |
| Treatment of data uncertainties | Document uncertainty of data of positive and negative effects. |
| | Describe performance of measure for the worst/best case scenario. |
| | Evaluation tools may allow for inclusion of types of uncertainties (e.g. PROMETHEE) |
| | Refine criteria catalogue if no data is available at all. |
| **Step 5 Evaluation and prioritization** | |
| Determine whether and which evaluation software tool to be used. | CBA and/or MCA are supported by tools, such as e.g. Definite, D-Sight, SALDO, ADx, PRIMATE |
| | Analysis with the respective tool, presentation of the results and interpretation. |

# 5 Annex 2: Valuation techniques using conventional market-based methods for estimating potential economic benefits

Alessio Capriolo, ISPRA

## 5.1 Introduction

Potential economic benefits can be seen as the avoided damages emerging from action planning, generally in terms of ***avoided loss in profits (loss in flow values)*** or ***avoided loss in benefits (loss in stock values)***.

Two of the main types of conventional market-based technique considered in this Annex are: (1) changes in the inputs or outputs of marketed (and not marketed) goods or services (including ecosystem services); and (2) cost-based methods (including replacement costs and restoration costs)[21].

## 5.2 Valuation of Changes in Inputs/Outputs of marketed (and not marketed) goods or services

In terms of valuing changes in inputs/outputs, two situations must be distinguished from each other. These are:

**CASE 1** - changes in quantity do not result in changes in price; and

**CASE 2** - changes in quantity induce changes in price.

They both involve assumptions concerning the size of the expected change in output/inputs.

**CASE 1 – No Change in Prices**

If the change in output - denoted by $\Delta Q$ - is small relative to the current total market for Q, or the change in resource inputs is small relative to the market for that variable factor of production, then we can assume that the output and resource input prices will remain constant after the change in Q or R. In this case, we can simply multiply the expected change in output or inputs by market prices to derive a measure of the economic value (V) of the projected change. There are several ways of doing this.

[21] When the cost of a climate change impact cannot be measured directly – that is, the impact has no observable market price – we can base the valuation on supply or resource cost data. Estimates of the potential costs (or savings) to households and producers for example, can be obtained by using: the cost of replacing the good or service provided by the affected exposure unit after the climate change impact has occurred.

For changes in productivity, we can calculate a gross margin[22] for each unit of output, then multiply this by the projected change in output.

$V = \Delta Q * gm = (Q_k^1 - Q_k^0) * gm,$

where *gm* is the Gross margin $gm_k = P_k^0 - VC_k^0$

$P_k^0$ = the market price (adjusted, if necessary) for a unit of product k (the subscript '0' refers to the without climate change case), and

$VC_k^0$ = the variable costs of producing a unit of product k.

For changes in production costs, we can calculate the unit cost of variable factors (inputs), then multiply this by the projected change in resource use.

The economic value (V) of a decrement (increment) in production costs can be determined by multiplying the adjusted unit cost of a particular resource input (e.g. raw/potable water, agrochemicals, etc.) by the projected change in its use – that is:

$$V_i = \Delta R i * mc_i = (R_i^1 - R_i^0) * mc_i$$

where

$V_i$ = the economic value of the decrement (increment) in production costs associated with the use of resource input i ,

m$c_i$ = the adjusted marginal cost of resource input i,

$R_i^0$ = the projected use of resource input i in the without climate change case, and

$R_i^1$ = the projected use of resource input i in the with climate change case.

Alternatively, in both contexts, we can use Total (farm) Budgets (i.e. gross output minus gross input) for the 'with' and 'without' climate change cases.

[22] Market price in general is a proxy (but also a rather accessible data), while the Gross (or Net) margin should be the correct variable to be adopted to estimate the economic loss in productivity. Gross margin is simply the market value of output less the variable costs incurred in producing the output. Gross margin should not be mistaken for profit however. The profit derived from producing a commodity is generally equal to the market value of output less the total cost – i.e. variable plus fixed cost – of producing it. Fixed costs, in contrast to variable costs, do not vary in proportion to output, and include depreciation expense, rents, general overheads, etc. Variable costs, as the term implies, vary in proportion to output. The main variable cost components associated with, for example, crop production includes fertilisers, seeds, sprays, casual labour, etc. To utilise this valuation technique you must be able to quantify production/output – e.g. crop yields – with and without climate change. In general, if the change in output is not substantial, then fixed costs are unlikely to change. Nevertheless If fixed costs are expected to change, then the relevant fixed cost saving should also be deducted, and consequently in this case we are working with net margins, and not anymore with gross margins.

The net margin (or net income) (which we denote by ' Z ') from producing a given set of outputs can be represented by:

$$Z = \sum_{i=1}^{m}\left(Y_i \times P_{yi}\right) - \sum_{i=1}^{m}\left(X_j \times P_{xj}\right)$$

where

$P_{yi}$ is the adjusted price of output i and $P_{xj}$ is the adjusted price of input j.

Therefore, the cost (benefit) of an adverse (beneficial) climate change impact to producers is given by the change in net income margin – that is:

$$\Delta Z = Z_1 - Z_0$$

where the subscripts '0' and '1' refer to the <u>without</u> and <u>with</u> (climate change) case, respectively.

In the case of productivity changes, we can also estimate changes in land values (per hectare) for the 'with' and 'without' climate change cases.

Regardless of which approach we adopt, it is important to realise that market prices do not always reflect real opportunity costs. Distortions may exist due to the presence of indirect taxes, support prices, and other subsidies[23] and this is particularly relevant to the case of agriculture.

Usually property land value of areas under risk and discounted flows of farms income for the whole period of inactivity are alternative, depending on data availability. It is not recommendable to sum stock values to flows ones.

In several cases, the use of land values to estimate the benefits (change in productivity) of policy interventions – e.g. soil conservation or flood protection programmes – is however a well established approach.

In theory, the value of an asset, such as agricultural or forestland, a property, or a capital facility, is given by the present value of the projected stream of net benefits accruing from the use of the asset. In other words, the flow of net benefits from all the characteristics of the asset is aggregated in the price (or present value) of that asset. So, if one of the characteristics of the asset were to change as a result of climatic change – e.g. crop yields on agricultural land – the price of the asset will be affected, other things being equal. Therefore, by observing land (or property) values under the with and without climate change cases, we can approximate the economic value (V) of the projected change on 'productivity', as follows:

$$V_j = A_j * \Delta L_j^0 = A_j * (L^1_{j \to k} - L_j^0)$$

where

*Vj* = the economic value of the decrement (increment) in value of land use type j (e.g. agricultural or forestry land),

*A* j = the total affected area of land use type j (e.g. hectares of grazing land)

[23] In costing climate change impacts using market prices, we must make corrections for such distortions – for example, by deducting taxes from prices, or adding back subsidies.

$L_j^0$ = the adjusted market price of land use type j in the without climate change case, and

$L^1{}_{j \to k}$ = the adjusted market price of land use type j in the with climate change case[24]

Note that this approach is more appropriate to valuing the complete loss of land use j - e.g. from permanent loss of territory – or a switch from land use j to land use k - e.g. from one type of agricultural use to another, or from agricultural use to use as a mudflat or salt marsh.

Instead of using adjusted land values (market prices) to estimate possible climate change damages with this approach, you could equally use adjusted (annual) rental values. However, since the analysis is based on annual cost data in this case, it follows that the damage cost estimates produced are also (recurring) (annual) costs; as opposed to the 'one-off' (non-recurring) costs estimated using data on the market price of land. Remember not to add capitalised (non-recurring) values to annual (recurring) values.

---

**CASE 2 – Induced Price Changes**

In some situations, the change in output may be considerable relative to the current total quantity of output available in the marketplace. This in turn may induce the price of the affected good/service to change[25]. If the change in output is large enough to affect market prices, then we must resort to the relevant supply and demand curves in order to value ΔQ. In order to evaluate the induced change in price some information on the **price elasticity of demand** for the affected marketed good/service is needed. Then, if we can assume that the demand curve is linear over the projected change in quantity, the economic value of the change in output can be calculated using the method outlined.

---

**Price Elasticity of Demand**

**General Procedure:**

In economics, the price elasticity of demand for, say, good X measures the percentage change in the quantity demanded associated with a percentage change in price. Mathematically,

$$\xi = \frac{(\Delta Q / Q^0)}{(\Delta P / P^0)} = \left(\frac{\Delta Q}{\Delta P}\right) \times \left(\frac{P^0}{Q^0}\right)$$

where $\Delta P = P^1 - P^0$ and $\Delta Q = Q^1 - Q^0$

[24] If the land is permanently lost, its value in the with climate change case is equal to zero. Even if the land is lost to agricultural production, it does not necessarily mean it has no value to society. For example, flooded agricultural land may create a valuable mudflat or freshwater wetland, which has value. The value of the land in its new use, regardless of what that may be, should also be taken into account.

[25] If the deterioration in water quality decimated fish populations and subsequently had a large impact on harvest rates, fish might become scarce in the local markets. In such circumstances, other things being equal, it is likely that consumers would be willing to pay increasingly higher prices for the fish – as 'old' demand exceeds 'new' supply. This would have the effect of bidding up the price of fish.

Hence, given ξ, $Q^0$, $Q^1$ and $P^0$, the above equation can be solved for $\Delta P$, from which $P^1$ can be derived, since $\Delta P = P^1 - P^0$

## 5.3 Examples of economic assessment of (direct and indirect) climate change impacts

The following tables summarize the main elements allowing an economic assessment of climate change *impacts that might be avoided (potential benefits)*, either direct or indirect one, following as much as possible the scheme provided by the IPCC TAR (IPCC 2001) and AR4 (IPCC 2007).
Impact areas are: agriculture, energy, extreme events, human health, human settlements and infrastructures, ecosystems, and insurance.
Since it has to be considered that all the quantifications should be made against an ideal situation "without climate change", it is almost always introduced the expression: "absolute or % change in …"

| | **Agriculture (*)** |
|---|---|
| | **Direct impacts** |
| 1 | Absolute or % change in crop yield (physical output per unit of surface e.g. ton per hectare) per crop per area, or in crop production per crop (per area) times (x) the commodity price |
| | **Indirect impacts** |
| 2 | Absolute or % change in land prices<br>Property land value areas under risk and discounted flows of farms income for the whole period of inactivity are usually alternative, depending on data availability. |
| 3 | Absolute or % change in farms' income (discounted flows for the whole period of inactivity) |
| 4 | Restoration costs |

(*) With appropriate modifications this can be applied to fishery and livestock

| | Energy Demand and Industries (*) |
|---|---|
| | **Direct impacts** |
| 1 | Absolute (e.g. Mw/h) or % change in "average" households' (*) energy demand by vector (coal, oil, gas, oil products, electricity). This can be measured with different time resolutions: yearly, quarterly (seasonal), monthly |
| 2 | Absolute or % change in peak consumption (i.e. in frequency, intensity, duration of peak loads). |
| 3 | Absolute or % change in energy expenditure (implies associating energy prices to 1 and/or 2) |
| 4 | Estimated % change in tourism expenditure following climate scenarios in order to estimate the change in tourism expenditure, i.e. change in arrivals x n. of days (stays) x average daily expenditure (direct sales for sectors or business involved) |
| | **Energy Supply and Industries (*)** |
| | **Direct impact** |
| 5 | Absolute (e.g. Mw/h) or % change in electricity production (from hydro or nuclear sources) due to changes in water availability. |
| 6 | Increase in the risk (n°, frequency, duration and associated energy supply-demand gap) of electricity supply breakages from overloads in peak demand, and value of loss for power outage |
| 7 | Increase in the risk (n°, frequency, duration and associated energy supply-demand gap) of energy supply breakages due to stress on energy network infrastructures from extreme events, including extreme temperatures, and value of loss for power outage. |
| 8 | Absolute or % change in the value of lost production under 5, 6,7 (implies associating energy prices to 5, 6 and 7)<br>(*) With appropriate modifications this can be applied to "other industries": discounted flows of lost production value for the whole period of inactivity. |
| 9 | (*) Absolute or % change in costs for industrial installation recovery and replacement<br>Maintenance costs due to extreme events including extreme temperatures, are mainly referred to the concept of adaptation cost |
| | **Indirect impacts (for energy demand and supply)** |
| 10 | Potential re-composition of the energy mix |
| 11 | Absolute or % change in energy sector employment (n° of employed in the sector) |

| | Human health |
|---|---|
| | **Direct impact** |
| 1 | Absolute or % change in: |
| 1a | Mortality associated to different diseases |
| 1b | Morbidity associated to different diseases |
| 1c | Mortality and number of injured if extreme events |
| 2 | Absolute or % change in Disability Adjusted Life Year: years of life lost + years of life diseased. It is an aggregated measure of 1a and 1b. (It implies a consideration of the age structure of the group affected) |
| 3 | Absolute or % change in the value of DALY (implies associating to a year of life lost or diseased an economic evaluation that can be based on, e.g. yearly per capita income, or on the value of a statistical life)<br>Undiscounted flow of: Number of victims x residual working life (65 years is on average the maximum working life) x average daily wage (usually National Statistics report data on average hourly wage that must be multiplied by 8 hours per day) x 240 days (that are the working days per year) |
| 4 | Absolute or % change in the value of hours/days of labour lost<br>In order to calculate the value of lost days/ hours at work: number of expected days lost for health problems x average daily wage (usually National Statistics report data on average hourly wage that must be multiplied by 8 hours per day)<br>Alternatively sufficient indicator to estimate the lost productivity: number of expected exposed people x n. of days lost for health problems / total population at work x 240 days |
| 5 | Absolute or % change in public and private health expenditure (treatment costs including hospitalization cost)<br>Number of people x expected hospital days x daily medical expenses.<br>Costs covered by insurance: It is worth stressing the importance to avoid double counting. This is particularly relevant when insured losses are considered. What paid by insurance companies should not be added to other costs, but replace that part of medical expenses (or damages etc.), which they cover. Insurance is indeed a cost (risk) transferring mechanisms. |
| 6 | Wage risk approach (estimate a major wage premium given to employee to bear an additional health risk) |
| | **Indirect impacts** |
| 7 | Absolute or % change in the value of lost production (implies linking mortality and morbidity to labour productivity and then to production) |

| | |
|---|---|
| | **Human Settlements and infrastructures** |
| | **Direct impact** |
| 1 | Absolute or % change in the value of properties lost<br>It can be referred to buildings. These can then be classified by type/function (e.g. residential, commercial, other) and per severity of damage (e.g. total disruption, partial etc.). It can refer to buildings with cultural, historical, artistic value.<br>Case: The decay of a monument is mainly due to climatic and environmental conditions of the area where the item is placed (territorial hazard); the effects usually depend on composition and nature of materials constituting cultural heritage. The territorial hazard might be represented by the dissolution of limestone materials (material loss expressed as surface recession R) (Bonazza A. et al, 2009).<br>For elaborating this parameter the damage function[26] (4) was applied (De la Fuente D et al, 2011):<br>$R = 4 + 0.0059 \cdot SO2 \cdot RH60 + 0.054 \cdot [H+] \cdot Rain + 0.078 \cdot HNO3 \cdot RH60 + 0.0258 \cdot PM10$<br>This approach describes the impacts produced by the synergistic action of atmospheric pollution and climatic factors on stone materials; on the other hand, it does not provide information about the effects of intense precipitation events, because the applied algorithm considers the total annual quantity of precipitation.<br>Note the economic valuation (in terms of restoration costs) is very much site-specific starting from the estimate of monument decay |
| 2 | Disruption in the infrastructures' network service (e.g. n° of days without energy, transportation, water etc.) |
| | **Indirect impacts** |
| 3 | Absolute or % change in the value of the lost production /cost of delay in delivery of goods (industrial, agricultural, service) due to infrastructure network services interruption |
| 4 | Absolute or % change in recovery and replacement costs.<br>Maintenance costs are closely related to the concept of adaptation cost*: The increase in average maintenance costs includes the potential increased frequency in building lifelong maintenance operations, required by higher exposure to environmental pressures. This concept refers to the potential additional cost required to put in practice specific preventive measures against building deterioration, e.g. particular treatments (painting, insulation, water proving) of indoor/outdoor walls, windows, doors, electric apparels etc. Information on both maintenance costs and adaptation costs can be retrieved from operators in the building sectors. All these costs need to be determined per the typical "events" (extreme rain, storm, flood etc.). Then their average increase depends on the climatic scenario considered and on the related change in the rate of occurrence and potentially intensity of the damaging events analysed.* |
| 5 | Costs for temporary accommodation of displaced people |
| 6 | Absolute or % change in the value of immobile properties (land in different uses e.g. agricultural, housing) |

[26] R = surface recession (?m/anno); $SO_2$, $HNO_3$, $PM_{10}$ = dioxide sulphur, nitric acid, particular matter concentrations (?g/m$^3$); $Rh_{60}$= relative humidity when RH>60 otherwise 0; [H+] = H+ concentrations (mg/l); Rain = amount of precipitation (mm/anno). Unlike to $PM_{10}$ and $SO_2$ concentrations, the nitric acid ($HNO_3$) concentrations are not usually measured by air quality monitoring stations, so they are estimated starting from nitrogen dioxide ($NO_2$) and ozone ($O_3$) concentrations, Relative Humidity (RH) and temperature (T) by the following formula: $HNO_3$ = 516•e-3400/(T+273) ([$NO_2$]•[ $O_3$]•Rh) 0.5.

| | Extreme Events[27] |
|---|---|
| | **Direct impact** |
| 1 | Absolute or % change in the number of people affected "on event" or "post event", e.g. because of sanitation problems like those induced by water, food contamination etc.<br>These usually are classified in: deceased, injured, displaced. Also changes in mortality, morbidity, due to physical + mental illnesses need to be taken into account. |
| 2 | Absolute or % change in Disability Adjusted Life Year: years of life lost + years of life diseased. It is an aggregated measure of the different variables included in point 1 (It implies a consideration of the age structure of the group affected) |
| 3 | Absolute or % change in the value of DALY (implies associating to a year of life lost or diseased an economic evaluation that can be based on e.g. yearly per capita income, or on the value of a statistical life)<br>Undiscounted flow of: Number of victims x residual working life (65 years is on average the maximum working life) x average daily wage (usually National Statistics report data on average hourly wage that must be multiplied by 8 hours per day) x 240 days (that are the working days per year) |
| 4 | Absolute or % change in the value of hours/days of labour lost<br>In order to calculate the value of lost days/ hours at work: n° of days lost for health problems x average daily wage (usually National Statistics report data on average hourly wage that must be multiplied by 8 hours per day)<br>Alternatively sufficient indicator to estimate the lost productivity: number of expected exposed people x n. of days lost for health problems / total population at work x 240 days |
| 5 | Absolute or % change in public and private health expenditure (treatment costs including hospitalization cost)<br>Number of people x hospital days x daily medical expenses |
| 6 | Wage risk approach (estimate a major wage premium given to employee to bear an additional health risk) |
| 7 | Absolute or % change in the value of properties lost (considering different uses e.g. agricultural, urban, housing etc.)<br>It can refer to buildings. These can then be classified by type/function (e.g. residential, commercial, other) and per severity of damage (e.g. total disruption, partial etc.). In case of buildings with cultural, historical, artistic value, in addition to the commercial value, non market values can be assessed (see 11 below)<br>It can refer to other properties mobile or immobile. |
| 8 | Disruption in the infrastructures' network service (e.g. n° of days without energy, transportation, water etc.) |
| 9 | Absolute or % change in the value of the lost production in different sectors (industrial, agricultural, service) due to service interruption/ or Cost of delay |

[27] For more comprehensive insights see "Assessing the costs of natural hazards, V. Meyer 2013" Nat. Hazards Earth Syst. Sci., 13, 1351–1373, 2013.

| | Indirect impacts |
|---|---|
| 10 | Absolute or % change in restoration costs |
| 11 | Non market costs associated to loss of intangible goods |

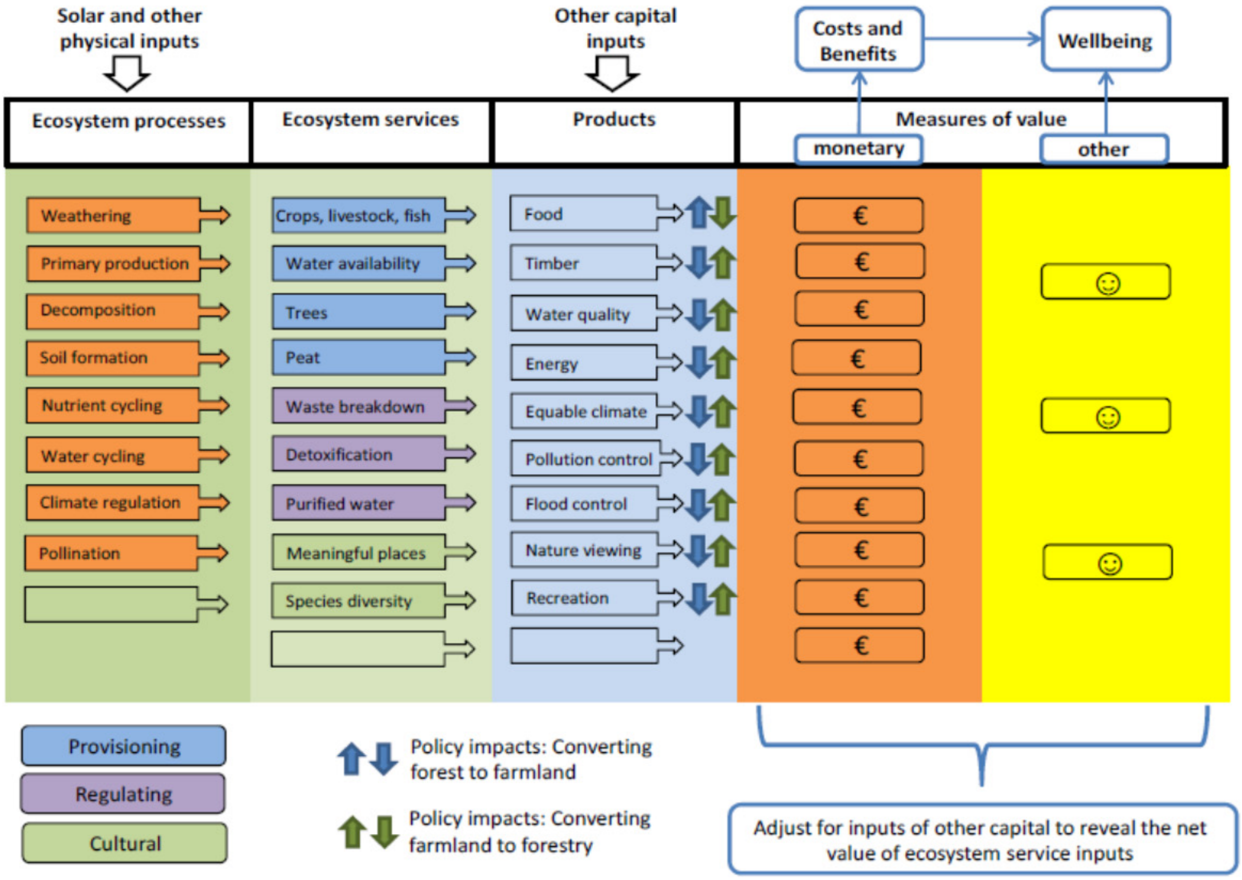
| | **Insurance** |
|---|---|
| | **Direct impact** |
| 1 | % Change in insurance premium related to extreme climatic/weather events |
| 2 | % Change in insured losses related to extreme climatic/weather events |
| | **Indirect impacts** |
| 3 | Number of insurance companies failing because of or refusing to insure climatic/weather extreme events |

| | Ecosystems |
|---|---|
| | **Direct impact** |
| 1<br>1a<br>1b<br>1c<br>1d | Absolute or % change in ecosystems provisioning service in, e.g.<br>Total fish catch or fish catch per unit of effort<br>Total timber (and other forest products) production or<br>Timber (and other forest products) production per hectare<br>Total production or yield of any other genetic materials<br>1a, 1b, 1c (and 1d, if feasible) may be then economically evaluated attaching market prices to the products |
| 2 | Absolute or % change in ecosystems' recreational services, e.g.<br>Estimated % change in tourism expenditure following climate scenarios: change in arrivals x n. of days (stays) x average daily expenditure (direct sales for single activities)<br>Under free access, revealed preferences methods are used:<br>- Hedonic pricing (implies to have property values in two similar locations just differing for the ecosystem component: Average house price in impacted region x Relevant Premium for environmental quality x Number of affected houses in impacted region)<br>- Travel cost (implies to have information on number of people, time and money spent to reach a given "ecosystem rich" location) |
| 3<br>3a<br>3b<br>3c<br>3d | Absolute or % change in the ecosystems' regulating service in, e.g.<br>Carbon sequestration (each ton can be economically evaluated at the marginal cost of carbon)<br>Protection from hydro-geological risk (that can be economically evaluated considering the protection expenditure that would be needed without the ecosystem as a buffer)<br>Pollination (market price through induced effect on agriculture productivity)<br>Water purification |
| | **Indirect impacts** |
| 4 | Loss of non-use value associated to existence value, cultural identity, option values. All quantifiable in money terms through Contingent Valuation or Choice Experiments methodologies. |

**ECOSYSTEM SERVICES**

For a more comprehensive description of the *ecosystem services*, please consider the following tables from A synthesis of approaches to assess and value ecosystem services in the EU in the context of TEEB (Bateman I. et al, 2013), or Liquete C, Piroddi C, Drakou EG, Gurney L, et al. (2013) Current Status and Future Prospects for the Assessment of Marine and Coastal Ecosystem Services: A Systematic Review.

**Conceptual framework for the economic valuation of ecosystem service flows (A synthesis of approaches to assess and value ecosystem services in the EU in the context of TEEB, Bateman I. et al, 2013)**



**Framework for valuation method of ecosystem services (A synthesis of approaches to assess and value ecosystem services in the EU in the context of TEEB, Bateman I. et al, 2013)**

| Services | Valuation Methods | Comments on Valuation Methods |
|---|---|---|
| **Provisioning** | | |
| Crops/timber | [red] [orange] | Most ecosystem services of agro-ecosystems will be capitalized in land prices. They should be adjusted for specific capital investments, such as for irrigation and drainage. Bio-economic modeling (production function method) can be used to estimate the value added of the provisioning service vis-à-vis other necessary input factors. |
| Livestock | [red] [orange] | |
| Wild foods | [red] | The market price of a close-substitute food or fuel might be a fair proxy. The cost of production should be subtracted. |
| Wood fuel | [red] | |
| Capture fisheries | [red] [orange] | The production function method is preferred, see Barbier (2007). Otherwise (adjusted) market prices can be used as a rough proxy, but the cost of other inputs to production should be subtracted. |
| Aquaculture | [red] [orange] | |
| Genetic | [red] [yellow] | Appropriate market prices are for example license fees for prospecting. An alternative valuation method is based on the costs of alternatives approaches to recover genetic information. |
| Fresh water | [red] [orange] [yellow] | Market prices (if available), shadow prices (through production function method). |
| **Regulating** | | |
| Pollination | [orange] [yellow] | Bio-economic modeling, accounting for the other input factors, including pollination is recommended. Alternatively, expenditures for alternative pollination technologies (replacement cost) might be used. |
| Climate regulation | [yellow] | The preferred cost-based method is 'damage cost avoided' |
| Pest regulation | [orange] [yellow] | Expenditure on manufactured pest regulation products (replacement cost) might be used |
| Erosion regulation | [orange] [yellow] | The preferred cost-based method is 'damage cost avoided', i.e. the loss in revenues as a result of soil erosion. |
| Water regulation | [yellow] [green] [blue] | Avoided expected damage costs of floods and droughts; revealed or stated preference methods might be used to estimate the willingness to pay to avoid these expected damages |
| Water purification | [yellow] [green] [blue] | Replacement cost might be used (see e.g. Chichilnisky and Heal, 1989), i.e. the costs of water purification by (often) public utilities or private drinking water companies. |
| Hazard regulation | [yellow] [green] [blue] | Avoided expected damage cost; revealed or stated preference methods might be used to estimate the willingness to pay to avoid these expected damages (accounting for risk aversion). |
| **Cultural** | | |
| Recreation | [green] [blue] | Methods include travel cost methods, contingent valuation, choice experiments |
| Aesthetic | [green] [blue] | Methods include hedonic price methods, contingent valuation, choice experiments |

| | |
|---|---|
| [red] | Market price based methods ((adjusted) market prices, net factor income,) |
| [orange] | Production function methods |
| [yellow] | Cost-based methods |
| [green] | Revealed preference methods (travel cost method, hedonic price methods) |
| [blue] | Stated preference methods (contingent valuation, choice experiments) |

**Liquete C, Piroddi C, Drakou EG, Gurney L, et al. (2013) Current Status and Future Prospects for the Assessment of Marine and Coastal Ecosystem Services: A Systematic Review**

| | | | | | |
|---|---|---|---|---|---|
| **Provisioning** | **Food provision** | Food | Food provision | Food | Terrestrial plant and animal |
| | | | | | Freshwater plant and animal |
| | | | | | Marine plant and animal |
| | **Water storage and provision** | Fresh water | N/A | Water | Potable water |
| | | | | | Water flow regulation |
| | | | | | Water quality regulation |
| | **Biotic materials and biofuels** | Ornamental resources | Raw materials | Ornamental resources | Biotic materials |
| | | Genetic resources | | Genetic resources | |
| | | Biochemicals | | Medicinal resources | |
| | | Fiber | | Raw materials | Renewable biofuels |
| **Regulating and maintenance** | **Water purification** | Water purification and waste treatment | Bioremediation of waste | Waste treatment | Bioremediation |
| | | | | | Water quality regulation |
| | | Nutrient cycling | Nutrient cycling | | Dilution and sequestration of wastes |
| | **Air quality regulation** | Air quality regulation | Gas and climate regulation | Air quality regulation | |
| | **Coastal protection** | Natural hazard regulation | Disturbance prevention | Moderation of extreme events | Mass flow regulation |
| | | Water regulation | | Regulation of water flows | Water flow regulation |
| | | Erosion regulation | | Erosion prevention | Air flow regulation |
| | **Climate regulation** | Climate regulation | Gas and climate regulation | Climate regulation | Atmospheric regulation |
| | **Weather regulation** | | N/A | | |
| | **Ocean nourishment** | Soil formation | | Maintenance of soil fertility | Pedogenesis and soil quality regulation |
| | | Nutrient cycling | Nutrient cycling | | |
| | **Life cycle maintenance** | Pollination | Biologically mediated habitat | Maintenance of life cycles of migratory species | Lifecycle maintenance and habitat protection |
| | | | | Maintenance of genetic diversity | Gene pool protection |
| | | | | Pollination | |
| | **Biological regulation** | Pest regulation | N/A | Biological control | Pest and disease control |
| | | Disease regulation | | | |
| **Cultural** | **Symbolic and aesthetic values** | Spiritual and religious values | Cultural heritage and identity | Spiritual experience | Spiritual |
| | | Cultural heritage values | | | |
| | | Cultural diversity | | | |
| | | Sense of place | | | |
| | | Aesthetic values | Feel good or warm glow | Aesthetic information | Aesthetic, heritage |
| | **Recreation and tourism** | Recreation and ecotourism | Leisure and recreation | Opportunities for recreation and tourism | Recreation and community activities |
| | | Social relations | | | |
| | **Cognitive effects** | Inspiration | Cognitive effects | Inspiration for culture, art and design | Information and knowledge |
| | | Knowledge systems | | Information for cognitive development | |
| | | Educational values | | | |

# 6 Annex 3: Case studies' economic evaluations of adaptation options

## 6.1 Timmendorfer Strand

Jenny Tröltzsch, Ecologic Institute

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

**What is the climate change related problem/risk you would like to reduce by adaptation?**

At the moment coastal flooding and storm surge events already endanger the community. The last severe storm surge hit the Lübeck Bay in 1872 and flooded the entire coastal lowlands of Timmendorfer Strand and Scharbeutz. Since then, the Baltic Sea coast has experienced minor storm surges only, when compared to the North Sea coast for instance.

For the Timmendorfer Strand case study a damage potential analysis has been developed. Two extreme flooding scenarios have been analysed, storm surges of 2.50 m and 3.00 m above mean sea level. For the lower scenario ca. 500 inhabitants would be affected, for the higher scenario ca. 2,000 inhabitants. The total estimated damages are 48 m EUR for the lower scenario and 117 m EUR for the higher scenario. For both scenarios the main damage components are building damages with ca. 58% of the total damage. Further relevant damages are loss of value especially for not offered tourism services like hotels, holiday apartments and restaurants, fixtures in buildings, equipment, vehicles and damages at transport infrastructure (Reese 2003) [28].

Reese (2003) indicates that the frequency of the storm surge events could increase with sea level rise. Two sea-level rises of 0.30 cm (minimum scenario) and 0.50 cm (maximum scenario) are used which are in line with moderate (RCP2.6) and medium (RCP4.5 und RCP 6.0)- IPCC projections.[29] For the 0.30 cm-sea level rise: the frequency of the storm surges is increasing by four, so a 100-year event could change to a 25-year event. For the 0.50 m-sea level rise: the frequency could increase by eight.

The tree alley on the promenade was originally a measure for coastal defence. However, as memories of the 1872 storm surge faded, coastal defence became less of a concern. By 1908, the first permissions were granted to construct buildings on the fore dunes, directly exposed to the sea (Herde, 2006: 14). Defence structures in form of natural beach-ridges were lower than what would be required to withstand the statistical 100-year storm surge, and attempts by state authorities to heighten defences through artificial structures (walls) were turned down by the municipalities (which are, as described above, the main decision-makers in coastal defence) in fear of reduced revenues from tourism as a consequence of limited sea views and narrowed beaches. (Hofstede, 2004: 235). As sea levels are rising, the need for new measures has become more and more urgent in the past decades.

The measure refers to coastal zones and following impacts from sea-level rise and increased storm intensity: coastal flooding and coastal erosion.

**Which adaptation tipping points can be identified?**

The tipping point of the measure will be reached by an increased number of extreme flooding events, similar to the 1872-event, because the dike is not high enough to protect the community and their values for such an event. The 1872-event reached 3.00m above sea level. As seen in 1872, events can already today reach the tipping point.

[28] Reese, Stefan (2003): Die Vulnerabilität des schleswig-holsteinischen Küstenraumes durch Sturmfluten. Kiel.
[29] IPCC-projections (2013) are between 0.26 and 0.98 m sea level rise. For the Baltic Sea also land rise is expected, so that the maximum will probably not be reached at the Baltic Sea.

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

**What are the alternative adaptation measures?**

Objectives of the measure are reducing the damages by storm surges by protection of human health and economic infrastructure. Maintaining tourism was a precondition for building the dike, because the community is economically highly relying on the tourism sector. Therefore, the measure had also the secondary objective to maintain tourism.

In the participatory process within the community different dikes were discussed. The major difference between the different versions of the dike was the height of the dike. The biggest fear of the inhabitants and public authority was that tourism activities could be affected, which would influence the economic basis of the community. Another option was to not build the dike at all and therefore to introduce no measure.

In parallel to the realised coastal protection measure, a finishing and landscaping-project was implemented. The finishing and landscaping-project focused e.g. on the improvement of the beach promenade, two new boardwalks – established in the dunes - and recreational infrastructure, e.g. benches, playground. Because the effects of both projects are difficult to divide, both projects are evaluated together.

The business-as-usual option was to implement no further coastal protection (no dike).

**What are alternative adaptation pathways?**

The effect of the measure is limited to a storm flood with a water level of 2.50 above sea level (a.s.l.) Any time (already today) a higher storm surge can happen. The Storm flood from 1872 reached a water level of 3.00 m a.s.l. Under climate change conditions the quantity of these extreme events could increase.

Alternatives such as a higher dike were discussed in the participatory process before implementing the measure. The local community decided to take this risk in fear of the decreased attractiveness of the coastline for tourists (and therefore to protect their local economy).

Furthermore, a higher dike would also have a certain tipping point, but a lower number of events would reach the relevant intensity.

**Step 3 - Evaluation Criteria and Method**

**Step 3a Selection of evaluation criteria**

**Which evaluation criteria should be used?**

In the case study, costs and benefits of the implementation of coastal protection are quantified as far as possible. For two scenarios we calculated costs and benefits. Minimum scenario referred to a sea level rise of 0.30 m and according an increased frequency of flood events, maximum scenario shows a seal level rise of 0.50 m and the following increase in events. In general, the damages of a 2.50 m a.s.l.-flood event can be fully avoided with the implemented coastal protection. The damages from the 3.00 m – a.s.l. event can only partially be avoided by the coastal protection measure.

*Benefit:*

- Avoided flooding damages (avoided damage per event, for minimum and maximum scenario)
- Change of recreational function, tourism due to finishing and landscaping project:
    - Change of travellers to community -> Change of spendings per day (minimum + maximum scenario based on different spendings per day)
    - Change of turnover of restaurant owners (qualitative)
- Change of property values (minimum and maximum scenario)

*Costs:*

- Investment and maintenance costs (coastal protection measure + finishing and landscaping measure)

**Step 3b Selection of evaluation method(s)**

**What is the appropriate evaluation method?**

As much as possible costs and benefits will be estimated in monetary terms -> cost-benefit analysis.

Further effects will be described qualitative.

**Step 4 - Data collection**

**What are the costs and what are the benefits of the alternative adaptation options?**

*Benefits:*

Avoided flood damages: The avoided flood damages were based on a damage potential analysis, which was prepared during the preparation of the implementation of the measure. The damage potential analysis included data on damages (in monetary terms) for flood events with 2.50 and 3.00 m a.s.l. The further adjustment for an increase of sea level of 0.30m (minimum scenario) and 0.50 m (maximum scenario) are based on assumptions on the quantity of expected events. The assumptions are based on Reese (2003), on regional definitions of flood events at the Baltic sea[30] and on interviews with local stakeholders in the community.

Change of travellers to community -> Change of spendings per day: For the estimation of an influence of the improvement of the beach promenade with the coastal protection measure and the finishing and landscaping project regional and local statistical data from the community and neighbouring communities are analysed. As comparison basis, statistical data from other relevant/comparable touristic towns at the German Baltic Sea and German North Sea are analysed. The relevant towns for the comparison were identified in the interviews with the local stakeholders and community members.

Data for spending per day are based on published reports for the community Timmendorfer Strand, for the region Schleswig-Holstein and Germany.

Change of turnover of restaurant owners (qualitative): the data on a change of turnover of restaurants and cafes at the improved beach promenade is based on interviews with owners or staff members.

Change of property values: The property value change was analysed based on approximate values for land prices estimated by evaluators (Bodenrichtwerte). Regional data from the Bundesländer Schleswig-Holstein and Mecklenburg-Vorpommern was used.

*Costs:*

Investment and maintenance costs: Data from the local community and mainly the engineering company (which was responsible for the project) was used. The estimation of the maintenance costs was based on data from the literature.

**What is the evaluation time frame?**

Dikes are long-term investments with a lifetime around 100 years. For the estimation as time frame 2011-2100 was used.

**Which discount rate should be applied?**

The discount rate of the German national guideline of the German Federal Environmental Agency will be used. [31] It is 1.5% for long-term evaluation (more than 20 years). The guideline says that same discount rate should be is used for the whole time-period. For a sensitivity analysis the net present value and the benefit-cost-ratio is also estimated for 0%, 1% and 5%.

[30] Regelwerk Küstenschutz Mecklenburg-Vorpommern (2009): Übersichtsheft Grundlagen, Grundsätze, Standortbestimmung und Ausblick

[31] UBA (2012): Ökonomische Bewertung von Umweltschäden. Methodenkonvention 2.0 zur Schätzung von Umweltkosten. Dessau.

**How to deal with data uncertainty?**

For the estimation of the costs and benefits a minimum and a maximum scenario were developed, which show the results as a range. The minimum and the maximum scenario are differing from each other: in the impacts of the climate change, change of property value, additional tourism and maintenance costs.

**Step 5 – Evaluation and Prioritization**

**What is the ranking order of alternative adaptation options (measures, bundles of measures or pathways)?**

The cost-benefit analysis was executed for the implemented measure of a coastal protection dike in the community. The measure was compared to a Business-as-usual-scenario – with no implementation of the coastal protection measure and the finishing and landscaping project. The two different estimated scenarios differ in the impacts of the climate change (minimum: RCP2.6, maximum: RCP4.5 and RCP 6.0), change of property value, additional tourism and maintenance costs.

The results of the estimation are shown in the following tables.

**Table 6.1-1: Net Present Value and Benefit-Cost-Ratio for the discount rate of 1.5%**

| Discounted costs and benefits 2011-2100, rate: 1,5% | Min-Scenario RCP2.6 (in EUR) | Max-Scenario RCP4.5 and RCP 6.0 (in EUR) |
|---|---|---|
| **Costs** | | |
| Investment costs | 30,000,000 | 30,000,000 |
| Maintenance costs | 124,870 | 374,610 |
| *Total Costs* | **30,124,870** | **30,374,610** |
| | | |
| **Benefits** | | |
| Land value | 5,935,961 | 8,630,542 |
| Additional tourism | 44,787,422 | 71,953,563 |
| Avoided damage | 71,531,567 | 169,559,899 |
| *Total benefits* | **122,254,949** | **250,144,004** |
| | | |
| **Net Present Value** | **92,130,079** | **219,769,394** |
| **Benefit-Cost-Ratio** | **4.1** | **8.2** |

It can be seen that the investment-upfront costs are the major type of costs and the main type of benefits is avoided damages by storm surges. Also the additional tourism shows substantial benefits. The Net present value is for both scenarios positive and the Benefit-Cost-Ratio is higher than one.

The following tables show the results for the discount rates: 0%, 1% and 5%.

**Table 6.1-2: Net Present Value and Benefit-Cost-Ratio for a discount rate 0%, 1% and 5%**

| Discounted costs and benefits 2011-2100, rate: 0% | Min-Scenario (in EUR) | Max-Scenario (in EUR) |
|---|---|---|
| Net Present Value | 201,016,061 | 443,375,622 |
| Benefit-cost-ratio | 7.7 | 15.5 |
| | | |
| **Discounted costs and benefits 2011-2100, rate: 1%** | **Min-Scenario (in EUR)** | **Max-Scenario (in EUR)** |
| Net Present Value | 118,837,450 | 273,887,896 |
| Benefit-cost-ratio | 4.9 | 10.0 |
| | | |

| Discounted costs and benefits 2011-2100, rate: 5% | Min-Scenario (in EUR) | Max-Scenario (in EUR) |
|---|---|---|
| Net Present Value | 13,326,937 | 62,547,913 |
| Benefit-cost-ratio | 1.4 | 3.1 |

The estimation of the coastal protection measure shows that for all discount rates the Net present value is positive and the Benefit-Cost-Ratio is higher than one.

## What are the main lessons learnt from your case study?

**Transferable results?**

The results of the case study are only limited transferable. These can be explained by the local characteristic of the community Timmendorfer Strand. The community is a very much developed and frequented touristic community at the Baltic Sea. The values for land and property are quite high compared to neighbouring and other towns at the German Baltic Sea. Furthermore, the results are based on the combined implementation of the coastal protection measure and the finishing and landscaping-project.

**Lessons learnt with regard to the process of economic evaluation?**

The cost and benefits-analysis shows that the results are very much dependent on the expected climate impacts and uncertainties are incorporated at this stage. For sea level rise certain projections exist, but for coastal flooding the storm intensity is also highly relevant. For changes of storm quantity and intensity no reliable projections are available yet, for Northern Germany results of projections for storm intensity show a range between a decrease and an increase[32].

At the beginning, we tried to differentiate the effects between the coastal protection measure and the parallel implemented finishing and landscaping-project. But this was not possible, because both projects were implemented in parallel and changes could not be differentiated, e.g. stakeholder mainly did not differentiate between the effects of the two projects.

Furthermore, the discussions with local stakeholder and community members were very helpful and essential to frame the case study. The knowledge and experiences of local stakeholders was not only relevant for gathering the relevant data, but also for discussing possible assumptions.

**Feasibility of methods?**

Including the discussed uncertainties, the cost and benefit-analysis seems to show relevant results.

And might have been a useful tool in the process of communicating the project to local community.

**Important data sources?**

Important data source was a damage potential analysis, which was prepared before the implementation of the measures and estimated relevant endangered land and buildings by two scenarios of coastal flooding (2.50 m a.s.l. and 3.00 m a.s.l.). The data was then further adjusted to climate impacts.

Furthermore, local and regional data on the tourism in the local community and also cost data from the local community and the engineering office was essential.

[32] Norddeutsches Klimabüro (2015): Norddeutscher Klimaatlas: Sturmintensitäten. http://www.norddeutscher-klimaatlas.de/klimaatlas/2071-2100/jahr/sturmintensitaeten/norddeutschland/mittlereanderung.html

## 6.2 Green Roof, Czech Republic

Zuzana Harmáčková, Eliška Lorencová, David Vačkář, Blanka Loučková, CzechGlobe

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

**What is the climate change related problem/risk you would like to reduce by adaptation?**

*Which problems already exist, what is/are the current risk/s?*

Since the study area is situated in a national park, the most important threat linked to climate change is the deterioration of local valuable ecosystems due to increased temperatures, changes in precipitation regimes, more frequent wind storms and bark beetle outbreaks, etc. Concerning local population, local stakeholders perceive water shortages as the most important pressure, which might be potentially caused by climate change in the area in the future. This study aims to assess the costs and benefits of possible ecosystem-based adaptation measures, which could enhance the resilience of local ecosystems and address the issue of water shortages.

*Which assets and sectors are at risk under current climate variability?*

Since the study area presents a national park, the most threatened assets are natural ecosystems and related forestry and tourism sectors.

*Which adaptation or protection measures are already in place?*

None.

*How do these risks presumably change due to climate and socio-economic change?*

These risks are likely to be intensified and exacerbated by climate change such as changing temperature and precipitation regimes. Furthermore, the growing pressure on the economic utilization of the area in terms of tourism and forestry might further affect the state of local ecosystems.

*What are the main drivers, impacts and affected sectors?*

Impacts: Damages from extreme weather related events

Sectors: Biodiversity and ecosystems, Forestry, Tourism

*Which climate and socio-economic scenarios are used?*

In this case study, we applied the approach of *complex adaptation scenarios* to 2050, which incorporated various socio-economic and ecological aspects, namely:

1. Basic socio-economic dynamics – incorporated through the European ALARM scenarios, on which our local-specific scenarios were based. ALARM scenarios present a European-scale dynamic spatially explicit scenarios of land use and land cover change, modelled by extrapolating current population dynamics and expected development of international trade, according to EU environmental and agricultural politics (Rounsevell et al., 2006; Settele et al., 2005; Spangenberg, 2007; Dendoncker et al., 2006).
2. Land use and land cover change – incorporated through the ALARM scenarios introduced above and based on local-specific trends defined by stakeholders.
3. Adaptation measures to climate change – incorporated as distinctive bundles of land use-based adaptation measures for each scenario, participatively developed by the stakeholders.

Specifically, a set of three scenarios has been developed during a participative scenario workshop with local stakeholders, consisting of a Green scenario prioritizing nature conservation, a Red scenario prioritizing economic development and a Shared vision, characterized by sustainable economic development, maintained level of nature conservation and a focus on small-scale businesses and local production. Each of the scenarios was characterized by a different level of land use change and a different intensity of adaptation measures.

While the Red scenario complies with SSP5 storyline, building on the assumptions of population growth and economic development, the Green scenario and the Shared vision are in line with SSP2, presuming no rapid changes and a moderate socio-economic development extrapolating current trends. Since the economic indicators assessed in this study did not have a direct connection to the level and pace of socio-economic development, but solely to the level of investments in ecosystem-based adaptation measures, we considered the SSP scenarios more as the information basis for participative scenario development by local stakeholders. However, by incorporating three scenarios (Green, Shared vision and Red), based on both SSP2 and SSP5 storylines, we have covered the range of socio-economic assumptions used within the BASE project.

Additionally, a fourth Business-as-Usual scenario to 2050 was introduced as the baseline for comparison with the first three scenarios in the cost-benefit analysis. This scenario presumed that no substantial climate and land use/land cover change will be present in the study area and no adaptation measures will be implemented. In addition, ecosystem services were assumed to be provided at the same level as in the current landscape, and regular management costs were assumed to remain at the current level.

These scenarios were created and processed in a geographic information system platform and further used for ecosystem services modelling and the cost-benefit analysis.

The impact of climate change was not incorporated at the stage of scenario building, but later in the process, at the stage of ecosystem services modelling. The influence of climate change was incorporated through the RCP4.5 and RCP8.5 climatic projections provided by CMCC within the BASE project, specifically through the levels of precipitation and evapotranspiration, required in some of our ecosystem service models (namely nitrogen retention and hydropower production). The RCP4.5 and RCP8.5 scenarios were chosen since they present the basis of common base scenario storylines, developed within the BASE project and applied in the case studies. For the performance of each adaptation scenario under different climate futures, see the results section.

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

**What are the alternative adaptation measures?**

*What are the primary and secondary objectives of adaptation?*

The main objective is to maintain a favourable state of local ecosystems and to preserve natural ecosystem processes.

*What are potential measures to meet these objectives?*

Mainly ecosystem-based adaptation measures such as sustainable forest management, peat land and water course restoration and enhancement of ecosystem resilience, specifically the enlargement of core protection zones.

*What is your baseline option?*

Our Business-as-Usual (BaU) scenario assumes preserving the current state of landscape with no implementation of adaptation measures and actions. Furthermore, it assumes only negligible change in climate.

On the other hand, various adaptation options are included in the potential future adaptation scenarios (Green, Red and Shared vision), which are created and assessed in terms of ecosystem services provision within this case study.

*What is the ambition level of this baseline strategy?*

Our BaU scenario depicts the current strategy in the area, where no adaptation measures have been/are being implemented.

*Is current backlog of investments for adaptation measures included or excluded?*

A current backlog of investments for adaptation measures does not exist in the study area.

*Does it include only planned adaptation or also autonomous, non-planned adaptation?*

Our BaU scenario does not include the implementation of any adaptation measures.

*Are there complementary measures? Is it appropriate to bundle these measures?*

No complementary measures.

**What are alternative adaptation pathways?**

*What is the “sell-by”-date of the measures or bundles of measures?*

In this case study, we do not apply the concept of adaptation pathways.

*What would be alternative measures or bundles of measures at these “tipping points”?*

In this case study, we do not apply the concept of adaptation pathways.

**Step 3 - Evaluation Criteria and Method**

**Step 3a Selection of evaluation criteria**

**Which evaluation criteria should be used?**

*What are the relevant positive and negative properties of the measures (costs and benefits) to be considered in the evaluation process (economic, ecological and social effects)?*

In this case study, we quantified the costs and benefits of ecosystem-based adaptation measures, i.e. adaptation measures created by changing or influencing the state of ecosystems (e.g. the area of various ecosystem types, management intensities, etc.). For each scenario (Green scenario, Shared vision, Red scenario, BaU) we calculated the costs and benefits of a bundle of adaptation measures, corresponding to each scenario’s storyline. Specifically, each scenario assumed a different level of area occupied by forests, and different intensity of ecosystem restoration and forest management.

*Costs:*

1. Investment costs (peat-land restoration)
2. Maintenance and operation costs (sustainable forest management)
3. Infrastructure (paths for tourists and foresters, tourist information facilities, etc.)
4. Costs influenced by the provision of ecosystem services (sediment dredging, nitrogen removal) under two different climate scenarios (RCP 4.5 and 8.5)

*Benefits:*

1. Benefits generated by the provision of ecosystem services (carbon sequestration, hydropower production) under two different climate scenarios (RCP 4.5 and 8.5)
2. Benefits generated by the implementation of adaptation measures (timber sales, sales of services related to hunting)

*What is the appropriate unit to measure each of these criteria? Is the performance of the adaptation options measured in qualitative, monetary or other quantitative terms?*

Both costs and benefits have been measured in monetary terms.

**Step 3b Selection of evaluation method(s)**

**What is the appropriate evaluation method?**

Since all relevant costs and benefits were possible to assess in monetary terms, we conducted a cost-benefit analysis in this case study.

**Step 4 - Data collection**

**What are the costs and what are the benefits of the alternative adaptation options?**

For our study area, we have utilized following data sources:

**Table 6.2-1: Data sources for Cost-benefit analysis**

| Type of value: | Data source: |
|---|---|
| **Costs related to ecosystem services:**<br>The costs of adaptation measures related to the provision of ecosystem services were quantified using the InVEST suite of models. Specifically, the InVEST ecosystem-service models quantify the proportion of pollutants (discharged from a landscape through water run-off) reaching the stream network. The notion of ecosystem services here is incorporated in the way that the ecosystems are able to remove a part of pollutants from the run-off water and, thus, decrease the pollutant load finally reaching the streams. Therefore, the higher the intensity of the ecosystem service provided by the landscape, the lower the amount of pollutant reaching the stream. Subsequently, the pollutants reaching the stream (which have NOT been removed by the ecosystems) need to be removed through the process of artificial water purification. That incurs costs for the removal of pollutants, which were previously not retained by the landscape. Therefore, we added sediment dredging and nitrogen removal on the side of costs, because they in fact describe hypothetical costs spent on water purification in the future under different ecosystem service scenarios. The lower these costs (and the higher the level of corresponding ecosystem services), the better. If these numbers were moved to the benefit side, they would have to be transformed to their negative values, otherwise the interpretation would be incorrect. | |
| Sediment dredging | Result of ecosystem-service modelling with InVEST tools (see above). Economic value based on sediment dredging costs, derived from the database of public procurements administered by the Ministry of Regional Development of the Czech Republic. |
| Nitrogen removal | Result of ecosystem-service modelling with InVEST tools (see above). Economic value based on costs of nitrogen removal from water run-off, calculated within a Central European study by Rybanič et al. (1999). |
| **Costs of the implementation of ecosystem-based adaptation measures** | |
| Inland marshes and peat bogs restoration | Derived from available Annual reports of the Administration of the NP and PLA of Šumava. |
| Forest management, operation costs | |
| Maintenance of touristic paths (Infrastructure) | |
| **Benefits related to ecosystem services:** | |
| Hydropower production | Result of ecosystem-service modelling with InVEST tools, defined as the amount of hydropower generated owing to a water yield provided by adjacent ecosystems. Economic value based on the average subsidy for hydropower production specified by the Energy Regulatory Office of the Czech Republic. |
| Carbon sequestration | Result of ecosystem-service modelling with InVEST tools. Economic value based on social value of carbon, calculated for the Czech Republic in a study by Hönigová et al. (2012). |
| **Benefits of the implementation of ecosystem-based adaptation measures** | |
| Timber sales | Derived from available Annual reports of the Administration of the NP and PLA of Šumava. |
| Sales of services related to hunting | |

No existing CBA studies or damage/impact assessments are available for the area.

**What is the evaluation time frame?**

*What is the lifespan of the measure with the longest lifetime?*

Since we are planning to assess long-term ecosystem-based adaptation measures, the concept of longest lifetime is not applicable. Our modelling exercise within this case study was conducted to 2050.

**Which discount rate should be applied?**

*Which discount rate is recommended by national guidelines for climate change adaptation measures (or public investments)?*

No national guidelines for climate change adaptation are available. The discount rate for public investment projects has usually been around 5 % as recommended by European Commission. Therefore, a discount rate of 5% has been used in this case study. Additionally, we conducted a sensitivity analysis at 1% discount rate.

**How to deal with data uncertainty?**

We dealt with data uncertainty in several ways.

1. At the stage of scenario and ecosystem services modelling:
    a. We modelled the ecosystem services separately for two climatic projections, RCP4.5 and RCP 8.5. The difference between these two climate scenarios was taken into account in two ecosystem models which require climatic parameters, nitrogen retention and hydropower production.
    b. We subjected all model parameters to a thorough review of scientific sources. However, there are still a few unavoidable sources of uncertainty, namely in some the ecological parameters required by the models (soil parameters, carbon pools, nitrogen loading, erosion coefficients, etc.). Since for some of them only a single data source (map) is available, the degree of uncertainty originating from this point cannot be quantified.
2. At the stage of cost-benefit analysis:
    a. We calculated the costs and benefits for the mean, minimal and maximal marginal values of individual ecosystem services and management approaches (based on literature review)

**Step 5 – Evaluation and Prioritization**

**What is the ranking order of alternative adaptation options (measures, bundles of measures or pathways)?**

In this case study, we compared four scenarios, ranging from no implementation of adaptation measures and no land use change (BaU), limited level of adaptation measures and existing land use change (Red scenario), moderate adaptation measures and existing land use change (Shared vision) and extensive adaptation measures and existing land use change (Green scenario). All of these combinations were modelled (a) for two climate scenarios, RCP4.5 and 8.5, and (b) the mean, minimum and maximum marginal values of each ecosystem service and management option (based on literature review). The results are presented in the tables below.

**Table 6.2-2: Economic parameters used in the cost-benefit analysis**

| Type of NPV calculated | Value (in 2010 prices) | | | | Source |
|---|---|---|---|---|---|
| | Mean | Min | Max | Unit | |
| Nitrogen retention | 2.69* | - | - | EUR kg $N^{-1}$ $year^{-1}$ | Rybanič et al. (1999) |
| Sediment dredging | 25.64 | 12.10 | 52.91 | EUR $t^{-1}$ $year^{-1}$ | Czech public procurements in a database administered by the Ministry of Regional Development of the Czech Republic. |
| Carbon sequestration | 84* | - | - | EUR t $C^{-1}$ $year^{-1}$ | Hönigová et al. (2012) |
| Forest management, operation costs | 1,158,642 | 617,000 | 1,805,074 | EUR $year^{-1}$ | Annual reports of the Administration of the NP and PLA of Šumava. |
| Infrastructure | 794,721 | 327,667 | 1,250,306 | EUR $year^{-1}$ | Annual reports of the Administration of the NP and PLA of Šumava. |
| Hydropower production | 0.09 | 0.07 | 0.11 | EUR $kWh^{-3}$ $year^{-1}$ | Subsidies for energy generation in water hydropower plants specified by the Energy Regulatory Office of the Czech Republic. |
| Timber sales | 4,379,891 | 3,849,567 | 4,893,723 | EUR $year^{-1}$ | Annual reports and supplementary data provided by the Administration of the NP and PLA of Šumava. |
| Sales of services related to hunting | 35,956 | 31,129 | 39,407 | EUR $year^{-1}$ | Annual reports and supplementary data provided by the Administration of the NP and PLA of Šumava. |

Notes: For carbon sequestration and nitrogen retention, we based our analyses on national-specific marginal values (social costs of carbon and nitrogen removal costs); therefore, for these services we did not use a range of values and provide only one estimate per a climate projection.

**Table 6.2-3: Cost-benefit analysis at 5% discount rate for four scenarios under RCP4.5 and RCP8.5 (net present value 2006-2050, EUR)**

| | | | | Scenario | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | RCP4.5 | | | | RCP8.5 | | | |
| | | | | BaU | Green scenario | Shared Vision | Red scenario | BaU | Green scenario | Shared vision | Red scenario |
| Costs | Costs related to ecosystem services | Sediment dredging | mean | 2,929,467 | 2,198,942 | 2,950,440 | 3,017,797 | 2,929,467 | 2,198,942 | 2,950,440 | 3,017,797 |
| | | | min | 1,611,024 | 1,209,280 | 1,622,558 | 1,659,599 | 1,611,024 | 1,209,280 | 1,622,558 | 1,659,599 |
| | | | max | 6,045,174 | 4,537,680 | 6,088,454 | 6,227,449 | 6,045,174 | 4,537,680 | 6,088,454 | 6,227,449 |
| | | Nitrogen | | 908,170 | 808,004 | 922,164 | 973,388 | 908,170 | 808,098 | 922,339 | 973,610 |
| | Annual management costs | Inland marshes and peat bogs restoration | mean | 83,428 | 121,125 | 83,428 | 0 | 83,428 | 121,125 | 83,428 | 0 |
| | | | min | 36,757 | 53,366 | 36,757 | 0 | 36,757 | 53,366 | 36,757 | 0 |
| | | | max | 338,224 | 491,056 | 338,224 | 0 | 338,224 | 491,056 | 338,224 | 0 |
| | | Forest management, operation costs | mean | 21,623,473 | 11,312,768 | 19,779,485 | 24,765,350 | 21,623,473 | 11,312,768 | 19,779,485 | 24,765,350 |
| | | | min | 11,514,931 | 6,024,275 | 10,532,971 | 13,188,044 | 11,514,931 | 6,024,275 | 10,532,971 | 13,188,044 |
| | | | max | 33,687,688 | 17,624,413 | 30,814,899 | 38,582,489 | 33,687,688 | 17,624,413 | 30,814,899 | 38,582,489 |
| | | Infrastructure | mean | 14,831,696 | 7,759,510 | 13,566,892 | 16,986,733 | 14,831,696 | 7,759,510 | 13,566,892 | 16,986,733 |
| | | | min | 6,115,169 | 3,199,277 | 5,593,685 | 7,003,699 | 6,115,169 | 3,199,277 | 5,593,685 | 7,003,699 |
| | | | max | 23,334,180 | 12,207,760 | 21,344,308 | 26,724,622 | 23,334,180 | 12,207,760 | 21,344,308 | 26,724,622 |
| | Sum | | mean | 40,376,234 | 22,200,349 | 37,302,409 | 45,743,269 | 40,376,234 | 22,200,443 | 37,302,584 | 45,743,490 |
| | | | min | 20,186,051 | 11,294,203 | 18,708,135 | 22,824,731 | 20,186,051 | 11,294,297 | 18,708,309 | 22,824,952 |
| | | | max | 64,313,437 | 35,668,913 | 59,508,049 | 72,507,948 | 64,313,437 | 35,669,007 | 59,508,224 | 72,508,170 |
| | Sum of costs compared to baseline (BaU) | | mean | **0** | **-18,175,885** | **-3,073,825** | **5,367,034** | **0** | **-18,175,791** | **-3,073,650** | **5,367,256** |
| | | | min | **0** | **-8,891,848** | **-1,477,916** | **2,638,680** | **0** | **-8,891,754** | **-1,477,742** | **2,638,901** |
| | | | max | **0** | **-28,644,524** | **-4,805,387** | **8,194,512** | **0** | **-28,644,430** | **-4,805,213** | **8,194,733** |
| Benefits | Benefits related to ecosystem services | Hydropower production | mean | 222,694,639 | 240,161,096 | 240,614,386 | 241,806,653 | 222,694,639 | 235,866,462 | 236,348,595 | 237,635,915 |
| | | | min | 164,958,992 | 177,897,108 | 178,232,878 | 179,116,039 | 164,958,992 | 174,715,898 | 175,073,034 | 176,026,604 |
| | | | max | 274,931,653 | 296,495,180 | 297,054,797 | 298,526,732 | 274,931,653 | 291,193,163 | 291,788,389 | 293,377,673 |
| | | Carbon sequestration | | 0 | 66,758,122 | 2,484,392 | -57,227,934 | 0 | 66,758,122 | 2,484,392 | -57,227,934 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Annual market benefits** | **Timber sales** | **mean** | 81,740,906 | 42,764,450 | 74,770,277 | 93,617,811 | 81,740,906 | 42,764,450 | 74,770,277 | 93,617,811 |
| | | | **min** | 71,843,595 | 37,586,466 | 65,716,979 | 82,282,426 | 71,843,595 | 37,586,466 | 65,716,979 | 82,282,426 |
| | | | **max** | 91,330,452 | 47,781,420 | 83,542,054 | 104,600,712 | 91,330,452 | 47,781,420 | 83,542,054 | 104,600,712 |
| | | **Sales of services related to hunting** | **mean** | 671,032 | 351,064 | 613,808 | 768,532 | 671,032 | 351,064 | 613,808 | 768,532 |
| | | | **min** | 580,961 | 303,942 | 531,418 | 665,374 | 580,961 | 303,942 | 531,418 | 665,374 |
| | | | **max** | 735,439 | 384,760 | 672,723 | 842,298 | 735,439 | 384,760 | 672,723 | 842,298 |
| | **Sum** | | **mean** | 305,106,576 | 350,034,731 | 318,482,862 | 278,965,062 | 305,106,576 | 345,740,098 | 314,217,072 | 274,794,324 |
| | | | **min** | 237,383,547 | 282,545,638 | 246,965,667 | 204,835,905 | 237,383,547 | 279,364,427 | 243,805,823 | 201,746,469 |
| | | | **max** | 366,997,544 | 411,419,482 | 383,753,965 | 346,741,808 | 366,997,544 | 406,117,465 | 378,487,557 | 341,592,748 |
| | **Sum of benefits compared to baseline (BaU)** | | **mean** | **0** | **44,928,155** | **13,376,286** | **-26,141,515** | **0** | **40,633,522** | **9,110,495** | **-30,312,253** |
| | | | **min** | **0** | **45,162,091** | **9,582,121** | **-32,547,642** | **0** | **41,980,881** | **6,422,276** | **-35,637,078** |
| | | | **max** | **0** | **44,421,938** | **16,756,422** | **-20,255,736** | **0** | **39,119,921** | **11,490,014** | **-25,404,795** |
| **Benefits - Costs** | | | **mean** | 264,730,342 | 327,834,382 | 281,180,453 | 233,221,793 | 264,730,342 | 323,539,655 | 276,914,488 | 229,050,834 |
| | | | **min** | 217,197,496 | 271,251,434 | 228,257,533 | 182,011,174 | 217,197,496 | 268,070,130 | 225,097,514 | 178,921,517 |
| | | | **max** | 302,684,107 | 375,750,569 | 324,245,916 | 274,233,859 | 302,684,107 | 370,448,458 | 318,979,334 | 269,084,579 |
| **NPV (Difference to BaU), i.e. $NPV_{scenario} - NPV_{BaU}$** | | | **mean** | **0** | **63,104,040** | **16,450,110** | **-31,508,549** | **0** | **58,809,313** | **12,184,146** | **-35,679,508** |
| | | | **min** | **0** | **54,053,938** | **11,060,037** | **-35,186,322** | **0** | **50,872,634** | **7,900,018** | **-38,275,979** |
| | | | **max** | **0** | **73,066,462** | **21,561,809** | **-28,450,247** | **0** | **67,764,351** | **16,295,227** | **-33,599,528** |

**Table 6.2-4: Cost-benefit analysis at 1% discount rate for four scenarios under RCP4.5 and RCP8.5 (net present value 2006-2050, EUR)**

| | | | | Scenario | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | RCP4.5 | | | | RCP8.5 | | | |
| | | | | BaU | Green scenario | Shared Vision | Red scenario | BaU | Green scenario | Shared Vision | Red scenario |
| Costs | Costs related to ecosystem services | Sediment dredging | mean | 5,722,357 | 3,703,002 | 5,780,332 | 5,966,522 | 5,722,357 | 3,703,002 | 5,780,332 | 5,966,522 |
| | | | min | 3,146,938 | 2,036,419 | 3,178,821 | 3,281,214 | 3,146,938 | 2,036,419 | 3,178,821 | 3,281,214 |
| | | | max | 11,808,512 | 7,641,421 | 11,928,147 | 12,312,364 | 11,808,512 | 7,641,421 | 11,928,147 | 12,312,364 |
| | | Nitrogen retention | | 1,774,000 | 1,497,117 | 1,812,683 | 1,954,279 | 1,774,000 | 1,497,376 | 1,813,165 | 1,954,891 |
| | Annual management costs | Inland marshes and peat bogs restoration | mean | 163,992 | 238,095 | 163,992 | 0 | 163,992 | 238,095 | 163,992 | 0 |
| | | | min | 72,253 | 104,902 | 72,253 | 0 | 72,253 | 104,902 | 72,253 | 0 |
| | | | max | 664,843 | 965,262 | 664,843 | 0 | 664,843 | 965,262 | 664,843 | 0 |
| | | Forest management, operation costs | mean | 42,238,819 | 22,098,114 | 38,636,814 | 48,376,094 | 42,238,819 | 22,098,114 | 38,636,814 | 48,376,094 |
| | | | min | 22,493,015 | 11,767,687 | 20,574,875 | 25,761,236 | 22,493,015 | 11,767,687 | 20,574,875 | 25,761,236 |
| | | | max | 65,804,794 | 34,427,142 | 60,193,150 | 75,366,191 | 65,804,794 | 34,427,142 | 60,193,150 | 75,366,191 |
| | | Infrastructure | mean | 28,971,912 | 15,157,256 | 26,501,270 | 33,181,513 | 28,971,912 | 15,157,256 | 26,501,270 | 33,181,513 |
| | | | min | 11,945,237 | 6,249,398 | 10,926,581 | 13,680,873 | 11,945,237 | 6,249,398 | 10,926,581 | 13,680,873 |
| | | | max | 45,580,476 | 23,846,371 | 41,693,504 | 52,203,292 | 45,580,476 | 23,846,371 | 41,693,504 | 52,203,292 |
| | Sum | | mean | 78,871,080 | 42,693,583 | 72,895,092 | 89,478,408 | 78,871,080 | 42,693,843 | 72,895,574 | 89,479,020 |
| | | | min | 39,431,443 | 21,655,523 | 36,565,214 | 44,677,602 | 39,431,443 | 21,655,782 | 36,565,696 | 44,678,213 |
| | | | max | 125,632,625 | 68,377,313 | 116,292,328 | 141,836,127 | 125,632,625 | 68,377,573 | 116,292,810 | 141,836,738 |
| | Sum of costs compared to baseline (BaU) | | mean | **0** | **-36,177,497** | **-5,975,988** | **10,607,328** | **0** | **-36,177,237** | **-5,975,506** | **10,607,940** |
| | | | min | **0** | **-17,775,920** | **-2,866,229** | **5,246,159** | **0** | **-17,775,661** | **-2,865,747** | **5,246,770** |
| | | | max | **0** | **-57,255,312** | **-9,340,297** | **16,203,502** | **0** | **-57,255,052** | **-9,339,815** | **16,204,113** |
| Benefits | Benefits related to ecosystem services | Hydropower production | mean | 435,006,840 | 483,288,487 | 484,541,493 | 487,837,218 | 435,006,840 | 471,417,048 | 472,749,784 | 476,308,257 |
| | | | min | 322,227,289 | 357,991,472 | 358,919,625 | 361,360,902 | 322,227,289 | 349,197,813 | 350,185,025 | 352,820,931 |
| | | | max | 537,045,482 | 596,652,453 | 598,199,375 | 602,268,171 | 537,045,482 | 581,996,356 | 583,641,709 | 588,034,885 |
| | | Carbon sequestration | | 0 | 128,902,202 | 4,797,074 | -110,500,512 | 0 | 128,902,202 | 4,797,074 | -110,500,512 |
| | Annual market | Timber sales | mean | 159,670,900 | 83,535,142 | 146,054,624 | 182,870,986 | 159,670,900 | 83,535,142 | 146,054,624 | 182,870,986 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **benefits** | | **min** | 140,337,708 | 73,420,581 | 128,370,111 | 160,728,693 | 140,337,708 | 73,420,581 | 128,370,111 | 160,728,693 |
| | | | **max** | 178,402,910 | 93,335,181 | 163,189,222 | 204,324,746 | 178,402,910 | 93,335,181 | 163,189,222 | 204,324,746 |
| | | **Sales of services related to hunting** | **mean** | 1,310,778 | 685,761 | 1,198,999 | 1,501,234 | 1,310,778 | 685,761 | 1,198,999 | 1,501,234 |
| | | | **min** | 1,134,836 | 593,713 | 1,038,060 | 1,299,727 | 1,134,836 | 593,713 | 1,038,060 | 1,299,727 |
| | | | **max** | 1,436,590 | 751,582 | 1,314,082 | 1,645,326 | 1,436,590 | 751,582 | 1,314,082 | 1,645,326 |
| | **Sum** | | **mean** | 595,988,518 | 696,411,592 | 636,592,190 | 561,708,926 | 595,988,518 | 684,540,153 | 624,800,481 | 550,179,965 |
| | | | **min** | 463,699,833 | 560,907,968 | 493,124,870 | 412,888,810 | 463,699,833 | 552,114,310 | 484,390,271 | 404,348,839 |
| | | | **max** | 716,884,981 | 819,641,418 | 767,499,752 | 697,737,730 | 716,884,981 | 804,985,321 | 752,942,086 | 683,504,445 |
| | **Sum of benefits compared to baseline (BaU)** | | **mean** | **0** | **100,423,073** | **40,603,672** | **-34,279,592** | **0** | **88,551,634** | **28,811,963** | **-45,808,553** |
| | | | **min** | **0** | **97,208,136** | **29,425,037** | **-50,811,022** | **0** | **88,414,477** | **20,690,438** | **-59,350,994** |
| | | | **max** | **0** | **102,756,437** | **50,614,771** | **-19,147,251** | **0** | **88,100,339** | **36,057,105** | **-33,380,537** |
| **Benefits - Costs** | | | **mean** | 517,117,438 | 653,718,008 | 563,697,098 | 472,230,518 | 517,117,438 | 641,846,310 | 551,904,907 | 460,700,945 |
| | | | **min** | 424,268,390 | 539,252,446 | 456,559,656 | 368,211,208 | 424,268,390 | 530,458,528 | 447,824,575 | 359,670,626 |
| | | | **max** | 591,252,356 | 751,264,105 | 651,207,424 | 555,901,604 | 591,252,356 | 736,607,748 | 636,649,277 | 541,667,706 |
| **NPV (Difference to BaU), i.e. $NPV_{scenario} – NPV_{BaU}$** | | | **mean** | **0** | **136,600,570** | **46,579,660** | **-44,886,920** | **0** | **124,728,872** | **34,787,469** | **-56,416,493** |
| | | | **min** | **0** | **114,984,056** | **32,291,267** | **-56,057,181** | **0** | **106,190,138** | **23,556,185** | **-64,597,764** |
| | | | **max** | **0** | **160,011,749** | **59,955,068** | **-35,350,753** | **0** | **145,355,392** | **45,396,920** | **-49,584,650** |

*What are the uncertainties associated with the performance of the different options?*

The uncertainty analysis included calculation of CBA for two levels of discount rate (5% and 1%), for two climate scenarios (RCP4.5 and 8.5) and for different marginal values of ecosystem services and management (mean, minimum, maximum, based on literature review). In all cases, the Green adaptation scenario performed as the most beneficial, followed by the Shared vision. The Red scenario proved to be the most undesirable option. This ranking of scenarios has not changed while using different economic and climatic parameters.

Different climate scenarios influenced two aspects of the cost-benefit analysis: the level of nitrogen retention and hydropower production. Nevertheless, these did not substantially influence the final ranking of the scenarios.

*Is there and, if so, to what extent uncertainty in the ranking of options?*

The ranking of the options (the Green adaptation scenario performed as the most beneficial, followed by the Shared vision; the Red scenario proved to be the most undesirable option) was robust to the uncertainty analysis and remained the same for all parameterizations.

*Is it possible to determine which option most likely performs best or is it necessary to gather further information to reduce uncertainty?*

In terms of ecosystem-based adaptation to climate change, the Green scenario most likely performs the best.

## What are the main lessons learnt from your case study?

**Transferable results?**

The results of our case study are not easily transferable to other areas for several reasons:

1. We analysed solely ecosystem-based adaptation options.
2. All scenarios we used for the analyses stem from very specific local conditions (an extensive forested mountain ecosystem, national park and related restrictions, …).
3. The costs and benefits of ecosystem-based measures were quantified solely in terms of ecosystem services and management costs related to these measures.
4. The final results are based on a specific value of management costs in the study area.

**Lessons learnt with regard to the process of economic evaluation?**

1. The cost-benefit analysis focusing on ecosystem-based adaptation options brings several sources of uncertainty, which were, however, reduced by the sensitivity analysis:
    a. The uncertainty stemming from the parameterization and modelling procedures of ecosystem-service models.
    Since only two modules of the InVEST model require climatic data and the differences between RCP4.5 and 8.5 were not substantial in the study area, the overall impact of different climatic projections on the cost-benefit analysis was small.
    The remaining uncertainty stemmed mainly from the ecological inputs into the InVEST models. Regarding those we depend on available data sources, which unfortunately usually provide only single source value without confidence intervals (e.g. soil maps, rainfall erosivity and soil erodibility indices, etc.).
    b. The uncertainty stemming from economic inputs to the cost-benefit analysis such as the marginal value of abatement costs for various ecosystem services. We reduced this type of uncertainty by eliciting all marginal values from a thorough review of available data and calculating the cost-benefit analysis for mean, minimum and maximum marginal values.

We were more successful in reducing the uncertainty stemming from the economic evaluation (by calculating the costs and benefits at two discount rate levels and at different levels of marginal values) than in reducing the uncertainty stemming from modelling (by using two climate change scenarios).

2. The economic valuation was facilitated by close cooperation with local stakeholders, namely the Administration of the NP and PLA Šumava. Some data sources on management and operation costs used in our analysis are not publicly available.

**Feasibility of methods?**

The methods applied in this study, namely ecosystem services modelling with InVEST, and subsequent cost-benefit analysis based on the compilation of avoided costs/benefits of ecosystem services, management and operation costs, are data and time consuming, but feasible and widely applicable in the conditions of natural and semi-natural areas and national parks. The approach can be recommended in the cases where the implementation of ecosystem-based adaptation measures is considered.

**Important data sources?**

The most important data in this case study were:

1. Data needed for ecosystem services modelling, which included national-wide climatic, soil and hydrological datasets. Where national sources were not available, parameters were derived from international reports and research studies.
2. Economic data, derived from local sources (such as the Administration of the NP and PLA Šumava), which were vital for the feasibility of the cost-benefit analysis.

## 6.3 Jena - Reconstruction of the apartment complex Winzerberge

Oliver Gebhardt, UFZ

The Winzerberge reconstruction project aims at reconstructing the public area surrounding an apartment complex of 400 flats (see Figure 6.3-2) in the large housing estate of Winzerla in the south of Jena. The Department of City Planning is in charge of preparing the building project. The planners are supported by the private planning consultancy “plandrei”. Potentially relevant stakeholders are the residential building cooperatives (RBCs) owning the apartment complex and the residents. As the RBCs do not own the area surrounding their buildings they are not obligated to invest in its reconstruction. Residents are in this particular case also not involved the planning process as all tenants moved out before the reconstruction started. New lessee will only move in once the reconstruction process will be finished. As a consequence the Department of City Planning is the most important actor preparing the final decisions to be taken by the city council in 2015.

**Figure 6.3-1 Apartment complex Winzerberge**
Note: Area is marked red.
Source: Landsat Image, Google Earth Pro

On the basis of the winning concept of an architectural competition (see Figure 6.3-3) the Department of City Planning developed two drafts (see Figure 6.3-4 and Figure 6.3-5). For considering future climate change in today’s decision-making variations of these drafts, including different kinds of heat stress mitigating adaptation measures, are comparatively assessed using multi-criteria analysis. These assessments aim to support the design of drafts, which on one hand suit current and future climatic conditions best, but on the other hand also take into account additional factors such as financial and aesthetic aspects see (Table 6.3-4).

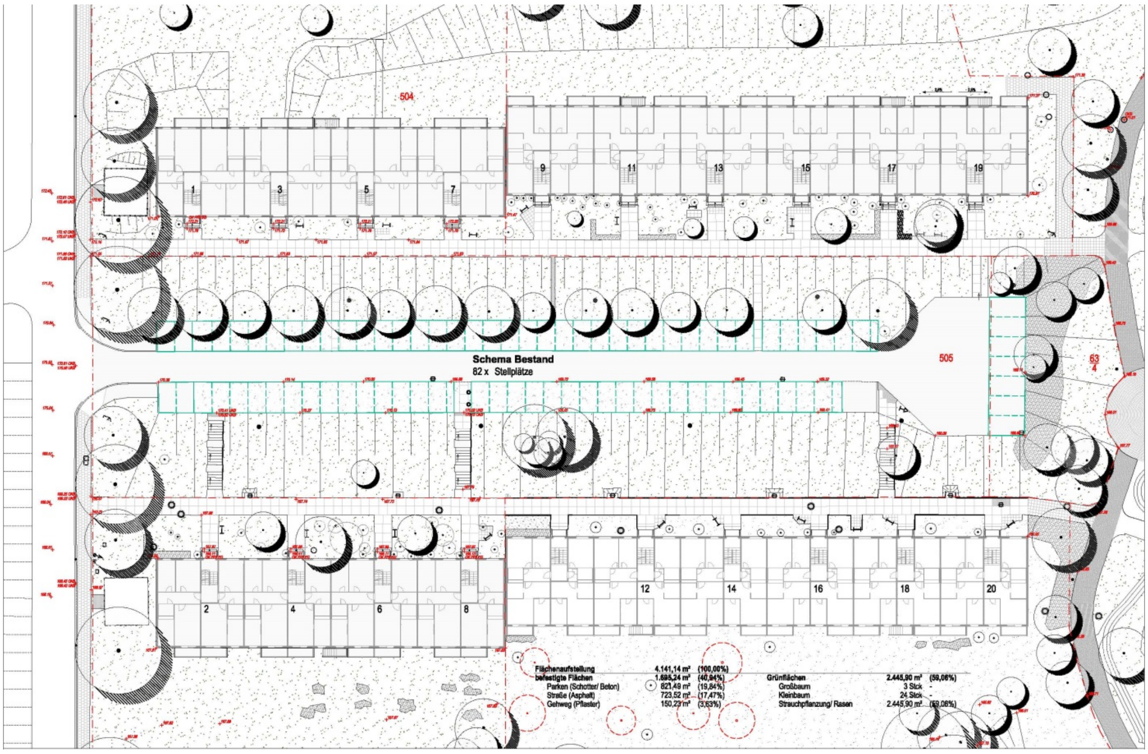



**Figure 6.3-2: Current status quo of the apartment complex Winzerberge**


**Figure 6.3-3: Winning concept of an architectural competition**

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

Jena is surrounded by steep shell limestone slopes, which operate as a thermal storage system making it one of the warmest places in Central Germany. Based on current climate projections an increase of heat stress events can be expected. Until the end of the century the average maximum temperature in summer will increase by 3 K (CMIP5, RCP 4.5) respectively 6 K (CMIP5, RCP 8.5) and the number of hot days will be up to three times (CMIP5, RCP 4.5) respectively four times (CMIP5, RCP 8.5) higher than under current climatic conditions. For the development of key parameters on the basis of different models and scenarios see Table 6.3-1. Despite the fact that the heat stress potential in Jena in general is lower in the suburban areas and the large housing estates located more distant to the city centre, a substantial increase of the number and intensity of heat stress events has been projected also for those areas.

**Table 6.3-1: Selected climatic parameters (1981-2010, 2021-2050, 2071-2100)**[33]

| | 1981-2010 | 2021-2050 WETTREG A1B | 2021-2050 STAR A1B | 2021-2050 CMIP5 RCP4.5 | 2021-2050 CMIP5 RCP8.5 | 2071-2100 WETTREG A1B | 2071-2100 CMIP5 RCP4.5 | 2071-2100 CMIP5 RCP8.5 |
|---|---|---|---|---|---|---|---|---|
| $T_{max}$ in summer quarter (°C) | 24 | 26 | 25 | 25.7 | 26.4 | 28 | 27.2 | 30.2 |
| Number of hot days ($T_{max}$ ≥ 30°C) | 11 | 19 | 20 | 18 | 22 | 39 | 35 | 49 |
| Precipitation in summer quarter (mm) | 160 | 185 | 170 | * | * | 175 | * | 135 |
| Number of sultry days (vapour pressure > 18,8 hPa) | 2.4 | 8.8 | 4.5 | - | - | 17.8 | - | - |

Note: *Standard deviation of natural variability of the parameter is higher than the signal determined by the model ensemble.

Changes in the site-specific heat stress potential under varying climatic conditions can be simulated using the modelling software Urban Heat Tool - URBAHT. The software uses an algorithm to process data on various structural and climatic factors (see Box 1), which can easily be obtained from public sources.[34] The rough estimates (Urban heat island – UHI potential scores) determined with URBAHT do not compare with those of established software packages for microclimatic modelling, e.g. Predicted Mean Votes determined with ENVI-met, but the tool's low data requests and immediate results facilitate its integration into established planning routines.

The UHI potential scores range from 0 - no heat stress to 10 - maximum heat stress level (see Box 1). Table 6.3-3 gives an overview of the results obtained for the Winzerberge area, i.e. the heat stress level for the status quo under current and future climatic conditions. Measurement data from the German National Meteorological Service (DWD) and climate projection data from the Coupled Model Intercomparison Project - Phase 5 (CMIP5)[35] for Representative Concentration Pathways (RCP) 4.5 and 8.5 provided by the KNMI Climate Explorer are used for the simulations. The scores indicate that present heat stress level is rather low but will increase substantially in future.[36]

[33] STAR (STAtistically based Regional climate model) and WettReg (WEaTher-Type based REGionalisation) are regional climate models which belong to the empirical statistical downscaling methods. Both models use global climate data from ECHAM5.
[34] For further information see Step 4 – Data collection.
[35] For further Information on CMIP5 see http://cmip-pcmdi.llnl.gov/cmip5/data_getting_started.html
[36] When interpreting the UHI potential scores one has to keep in mind that the scale is identical for all climate zones.

**Table 6.3-2: URBAHT heat stress potential scores of the Winzerberge area - status quo**

| Period | Status quo |
|---|---|
| **1981-2010** | 1.9 |
| **2021-2050** | |
| CMIP5 (RCP 4.5) | 2.9 |
| CMIP5 (RCP 8.5) | 3.3 |
| **2071-2100** | |
| CMIP5 (RCP 4.5) | 3.7 |
| CMIP5 (RCP 8.5) | 5.6 |

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

The two basic drafts developed by the Department of City Planning in cooperation with the private planning consultancy (see Figure 6.3-4 and Figure 6.3-5) are varied with regard to the use of tree species with different crown sizes and differently coloured pavements. A small-crowned (Sorbus intermedia „Brouwers“) and a large-crowned tree species (Tilia cordata „Greenspire“) have been selected from a recommendation list published by the Heads of the Departments of Park-keeping (Deutsche Gartenamtsleiterkonferenz – GALK). These tree species are considered to be adapted to the specific urban conditions as well as the changing climatic conditions. With regard to the optional colour schemes of the pavements it is assumed that either ordinarily coloured cobblestones with an albedo value of 0.3 or light-coloured material (0.5) are used.

On the basis of these variations the following alternatives are determined:

- Alternative 1 (D1TsPo): Draft 1, use of small-crowned tree species, ordinary pavement
- Alternative 2 (D1TsPl): Draft 1, use of small-crowned tree species, light-coloured pavement
- Alternative 3 (D1TlPo): Draft 1, use of large-crowned tree species, ordinary pavement
- Alternative 4 (D1TlPl): Draft 1, use of large-crowned tree species, light-coloured pavement
- Alternative 5  (D2TsPo): Draft 2, use of small-crowned tree species, ordinary pavement
- Alternative 6 (D2TsPl): Draft 2, use of small-crowned tree species, light-coloured pavement
- Alternative 7 (D2TlPo): Draft 2, use of large-crowned tree species, ordinary pavement
- Alternative 8 (D2TlPl): Draft 2, use of large-crowned tree species, light-coloured pavement

Table 6.3-3 gives an overview of the structural parameters of the 8 alternatives.

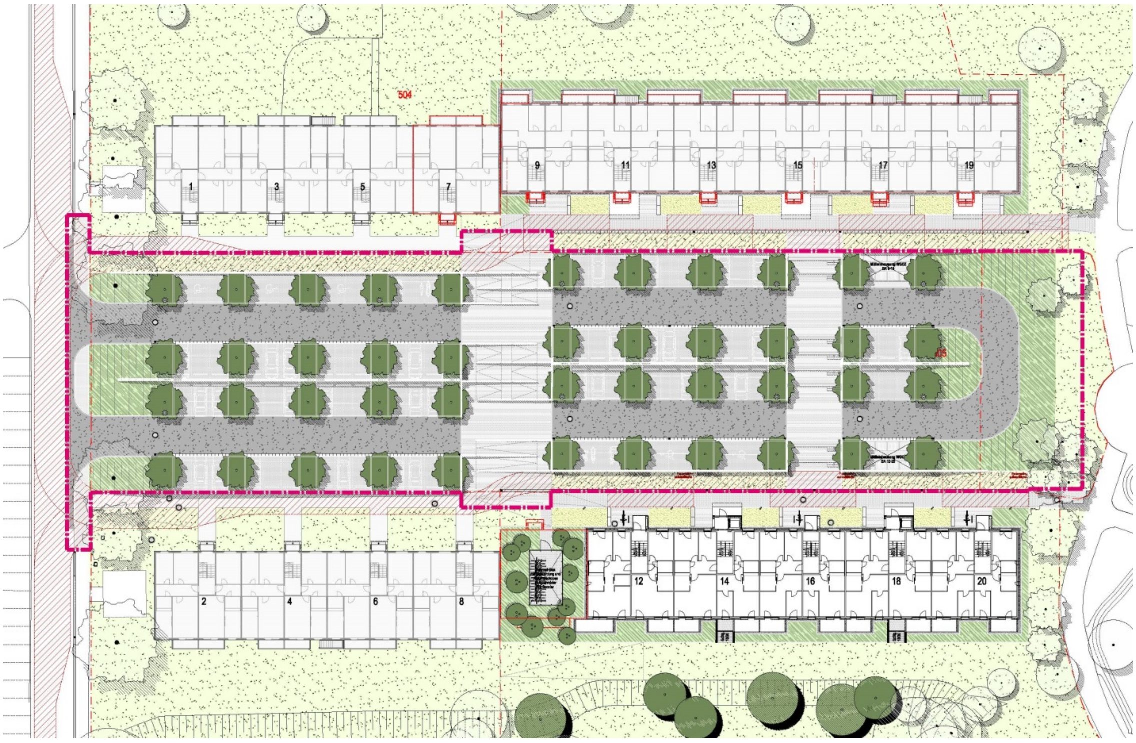



**Figure 6.3-4: Draft 1**

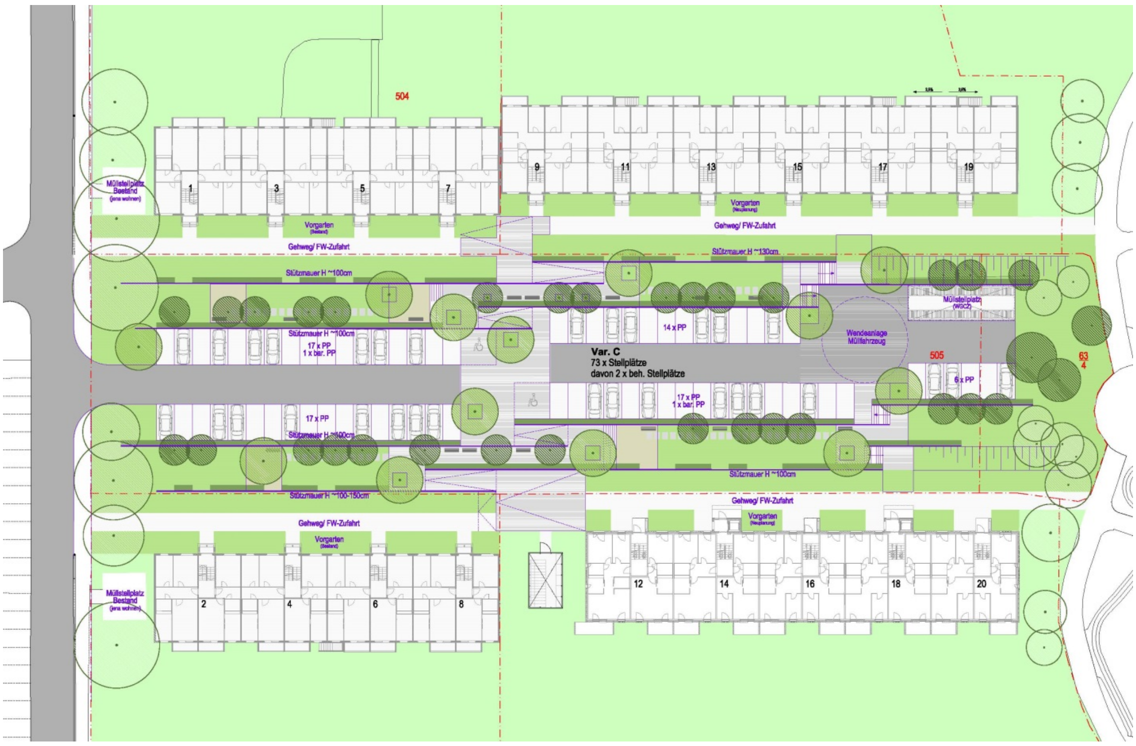



**Figure 6.3-5: Draft 2**

**Table 6.3-3: Structural parameters of the alternatives**

| Structural parameter | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 | Alternative 5 | Alternative 6 | Alternative 7 | Alternative 8 |
|---|---|---|---|---|---|---|---|---|
| Area type | open midrise | open midrise | open midrise | open midrise | open midrise | open midrise | open midrise | open midrise |
| Share of impervious area without buildings (%) | 29.5 | 29.5 | 29.5 | 29.5 | 27.5 | 27.5 | 27.5 | 27.5 |
| Share of area covered by buildings (%) | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 | 23.3 |
| Average height of buildings (m) | 19.8 | 19.8 | 19.8 | 19.8 | 19.8 | 19.8 | 19.8 | 19.8 |
| Construction type of buildings | in row | in row | in row | in row | in row | in row | in row | in row |
| Average albedo of surfaces (1981-2010) | 0.238 | 0.240 | 0.267 | 0.270 | 0.243 | 0.245 | 0.277 | 0.280 |
| Average albedo of surfaces (2021-2050) | 0.236 | 0.230 | 0.264 | 0.255 | 0.241 | 0.233 | 0.274 | 0.264 |
| Average albedo of surfaces (2071-2100) | 0.244 | 0.226 | 0.271 | 0.244 | 0.238 | 0.217 | 0.270 | 0.243 |
| Share of blue structures % | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Share of lawn area (%) | 46.4 | 46.4 | 46.4 | 46.4 | 47.6 | 47.6 | 47.6 | 47.6 |
| Share of area covered by bushes (%) | 0.8 | 0.8 | 0.8 | 0.8 | 1.7 | 1.7 | 1.7 | 1.7 |
| Share of area covered by trees (1981-2010) (%) | 14.0 | 12.6 | 14.0 | 12.6 | 14.3 | 12.9 | 14.3 | 12.9 |
| Share of area covered by trees (2021-2050) (%) | 15.8 | 20.5 | 15.8 | 20.5 | 16.3 | 22.4 | 16.3 | 22.4 |
| Share of area covered by trees (2071-2100) (%) | 17.8 | 32.1 | 17.8 | 32.1 | 18.5 | 35.2 | 18.5 | 35.2 |
| Irrigation of green structures in summer | yes | yes | yes | yes | yes | yes | yes | yes |

Notes: The average albedo has been calculated as the weighted sum of the albedo values of all surfaces. On the basis of the construction plans it has been assumed that for all variations of Draft 1 70% of the crowns of the trees cover lawn area and 30% cover pavements. The corresponding values for Draft 2 are 80% respectively 20%.

**Step 3 - Evaluation Criteria and Method**

**Step 3a Selection of evaluation criteria**

The following criteria are chosen to compare the alternatives:

Net present costs (monetary) consist of the investment costs and the maintenance costs of the green structures for 40 years (period 2015-2055) respectively 85 years (2015-2100). A rate of 3% p.a. is used for discounting. The UHI potential (quantitative) represents the heat stress level related to the respective alternative. It is determined with the URBAHT tool. The number of parking lots (quantitative), the architectural quality of the drafts (qualitative) and the amenity value (qualitative) for residents and guests are also considered for the assessment.

**Step 3b Selection of evaluation method(s)**

Several assessment methods accounting differently for various types of uncertainty can be applied to determine the most appropriate alternative. Empirical evidence shows that multi-criteria analysis (MCA) is a promising tool to support such decision processes in the field of climate change adaptation. Multi-attribute decision-making (MADM), a type of MCA, which compares pre-defined sets of alternatives are often used for applicability reasons. There are MADM concepts, which are based on multi attribute utility theory (MAUT) and so called outranking concepts, e.g. PROMETHEE, which perform pairwise comparisons of the criteria scores of all alternatives.

In contrast to MAUT approaches outranking concepts do not assume that decision-makers are completely aware of their preference structure. Furthermore, they can deal with uncertain, incomplete, differently scaled and inconsistent data. Applied in the traditional way, e.g. PROMETHEE I, they do not allow for compensation of positive and negative criteria scores. Thereby it is possible to discover unsolvable trade-off between alternatives. As PROMETHEE I provides partial pre-orders of alternatives, in these cases rankings will be incomplete. The advantage of identifying non-comparable measures is that the exchange amongst the different stakeholder-groups about the evaluation criteria and their weighting might be promoted. A complete ranking can be obtained if the so-called positive and negative preference flows are aggregated into net preference flows, which can easily be ordered (PROMETHEE II). If there are uncertainties in the criterion values which shall be considered in terms of score ranges, triangular distributions or any other probability functions Stochastic PROMETHEE II can be applied.

For the “Winzerberge” project multiple, differently scaled evaluation criteria are used to comparatively assess the alternative drafts. As for the determination of the UHI potential the RCPs 4.5 and 8.5 are used there is uncertainty concerning the performance of the alternatives with regard to this criterion. Therefore, **Stochastic PROMETHEE II** is applied for the assessment.

**Step 3c Weighting of evaluation criteria**

The residential building cooperatives are informed and rather informally involved in the decision making process concerning the reconstruction of the public area at the Winzerberge site. As the RBCs will only be looking for new tenants once the reconstruction of the apartment buildings will be finished no individual residents or resident associations take part in the planning process. Therefore, the employees of the Department of City Planning, who are in charge of the planning process, decide about the evaluation criteria as well as their weighting when balancing the alternative drafts. Therefore, the weights presented in Table 6.3-4 represent the preferences of the local planning authorities. Point allocation has been used to elicit criteria weights. Despite the fact that no formal consideration of stakeholder interests is taken place, planners apparently take into account their professional experiences, i.e. anticipating typical stakeholder interests, when making these decisions.

**Table 6.3-4: Weighting of evaluation criteria**

| Criteria | Weights |
|---|---|
| Heat stress potential | 25 |
| Costs | 20 |
| Parking lots | 10 |
| Amenity value | 30 |
| Architectural quality | 15 |

**Step 4 - Data collection**

The data used for the MCA comes from different sources. The private planning consultancy “plandrei” and the construction material company “Rinn Beton- und Naturstein” provide information on investment costs. **Maintenance costs** of the tree population are supplied by the municipal service company “KSJ”, which is responsible for taking care of the green structures on public premises in Jena. The locational **heat stress potential** (UHI potential) unfolding, if drafts are implemented, is estimated using the modelling software Urban Heat Tool - URBAHT (see Box 1). The data on the structural parameters is determined as the **number of parking lots** on the basis of existing plans. The climatic data for applying URBAHT comes from two sources. The measurement data is provided by the German National Meteorological Service (DWD) and CMIP5 climate projection data is been sourced from the KNMI Climate Explorer. Information regarding the alternatives’ performance concerning the criteria **architectural quality** and **amenity value** is collected through expert judgments from local planners.

**Box 1: Urban heat tool – URBAHT**

URBAHT is a tool for the assessment of site-specific heat stress levels under changing climatic conditions and/or for varying configurations of a spatial unit, e.g. as a consequence of the implementation of an urban planning project. On the basis of these assessments users can compare different situations in which either the climatic or the construction related parameters or both of them are change at the same time for the same spatial unit. In a single run any pair of the following 4 states can be compared with URBAHT:

| | Current climatic conditions | Future climatic conditions |
|---|---|---|
| **Current spatial configuration** | Current heat stress level | Heat stress level for future climatic conditions |
| **Changed spatial configuration** | Heat stress level for changed spatial configuration | Heat stress level for changed spatial configuration and future climatic conditions |

**Figure 6.3-6: Comparative assessments with URBAHT**

The software uses an algorithm to process data on various structural and climatic factors, which can easily be obtained from public sources. The following input data is requested:

**Table 6.3-5: Structural and climatic input parameters for URBAHT**

| Structural parameters | Climatic parameters |
|---|---|
| Area type | Global radiation |
| Construction type | Average maximum temperature in summer quarter |
| Portion of impervious area (without buildings) | Average precipitation in summer quarter |
| Portion of impervious area covered by buildings | Influence of cold air flows for site-specific micro climate |
| Average height of buildings | Average wind speed |
| Average albedo value of surfaces | |
| Portion of water areas | |
| Portion of green areas (lawn, bushes, trees) | |
| Irrigation of at least 50% of green areas in summer | |
| Total population of the city | |
| Population density of study area | |

The UHI potential scores determined with URBAHT range from 0 (no heat stress) to 10 (maximum heat stress level). The scale is identical for all climate zones. The scores do not reflect, as for instance predicted mean votes, specific levels of thermal (dis)comfort. Therefore, it is recommended to rather interpret changes or differences in UHI potential scores than the absolute heat stress level values.

| UHI potential score | Heat stress level |
|---|---|
| 0 | None |
| 1 | Very low |
| 2 | Low |
| 3 | Moderate |
| 4 | Medium |
| 5 | Slightly elevated |
| 6 | Moderatly elevated |
| 7 | Strongly elevated |
| 8 | High |
| 9 | Very high |
| 10 | Maximum |

**Figure 6.3-7: URBAHT UHI potential score scale**

Table 6.3-6 Heat stress potentials of alternatives for the periods 1981-2000, 2021-2050, 2071-2100

| Period | Alternative 1 | | | Alternative 2 | | | Alternative 3 | | | Alternative 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1981-2010** | | 2.1 | | | 2.1 | | | 1.8 | | | 1.8 | |
| **2021-2050** | | | | | | | | | | | | |
| CMIP5 (RCP 4.5) | | 3.0 | | | 3.0 | | | 2.8 | | | 2.7 | |
| CMIP5 (RCP 8.5) | | 3.5 | | | 3.4 | | | 3.2 | | | 3.1 | |
| **2071-2100** | | | | | | | | | | | | |
| CMIP5 (RCP 4.5) | | 3.8 | | | 3.5 | | | 3.6 | | | 3.4 | |
| CMIP5 (RCP 8.5) | | 5.6 | | | 5.4 | | | 5.4 | | | 5.2 | |
| **Minimum, mean, maximum value** | **Min** | **MV** | **Max** | **Min** | **MV** | **Max** | **Min** | **MV** | **Max** | **Min** | **MV** | **Max** |
| Period 2021-2050 | 3.0 | 3.3 | 3.5 | 3.0 | 3.2 | 3.4 | 2.8 | 3.0 | 3.2 | 2.7 | 2.9 | 3.1 |
| Period 2071-2100 | 3.8 | 4.7 | 5.6 | 3.5 | 4.5 | 5.4 | 3.6 | 4.5 | 5.4 | 3.4 | 4.3 | 5.2 |
| | **Alternative 5** | | | **Alternative 6** | | | **Alternative 7** | | | **Alternative 8** | | |
| **1981-2010** | | 1.9 | | | 2.0 | | | 1.6 | | | 1.6 | |
| **2021-2050** | | | | | | | | | | | | |
| CMIP5 (RCP 4.5) | | 2.9 | | | 2.8 | | | 2.6 | | | 2.5 | |
| CMIP5 (RCP 8.5) | | 3.3 | | | 3.2 | | | 3.0 | | | 2.9 | |
| **2071-2100** | | | | | | | | | | | | |
| CMIP5 (RCP 4.5) | | 3.7 | | | 3.4 | | | 3.5 | | | 3.2 | |
| CMIP5 (RCP 8.5) | | 5.6 | | | 5.3 | | | 5.3 | | | 4.7 | |
| **Minimum, mean, maximum value** | **Min** | **MV** | **Max** | **Min** | **MV** | **Max** | **Min** | **MV** | **Max** | **Min** | **MV** | **Max** |
| Period 2021-2050 | 2.9 | 3.1 | 3.3 | 2.8 | 3.0 | 3.2 | 2.6 | 2.8 | 3.0 | 2.5 | 2.7 | 2.9 |
| Period 2071-2100 | 3.7 | 4.7 | 5.6 | 3.4 | 4.4 | 5.3 | 3.5 | 4.4 | 5.3 | 3.2 | 4.0 | 4.7 |

**Table 6.3-7: Data matrix Winzerberge project**

| | Alternative 1 | Alternative 2 | Alternative 3 | Alternative 4 | Alternative 5 | Alternative 6 | Alternative 7 | Alternative 8 | IT[1] | PT[2] |
|---|---|---|---|---|---|---|---|---|---|---|
| **Net present costs** (2021-2050) | 1,057,977 | 1,057,977 | 1,060,234 | 1,060,234 | 1,100,077 | 1,100,077 | 1,102,472 | 1,102,472 | 10,000 | 500,000 |
| **Net present costs** (2071-2100) | 1,095,527 | 1,095,527 | 1,097,784 | 1,097,784 | 1,141,382 | 1,141,382 | 1,143,777 | 1,143,777 | 10,000 | 500,000 |
| | Min I MV I Max | Min I MV I Max | Min I MV I Max | Min I MV I Max | Min I MV I Max | Min I MV I Max | Min I MV I Max | Min I MV I Max | | |
| **UHI potential** (2021-2050) | 3.0 3.25 3.5 | 3.0 3.20 3.4 | 2.8 3.00 3.2 | 2.7 2.90 3.1 | 2.9 3.10 3.3 | 2.8 3.00 3.2 | 2.6 2.80 3.0 | 2.5 2.70 2.9 | 0 | 3 |
| **UHI potential** (2071-2100) | 3.8 4.70 5.6 | 3.5 4.45 5.4 | 3.6 4.50 5.4 | 3.4 4.30 5.2 | 3.7 4.65 5.6 | 3.4 4.35 5.3 | 3.5 4.40 5.3 | 3.2 3.95 4.7 | 0 | 3 |
| **Number of parking lots** | 78 | 78 | 78 | 78 | 75 | 75 | 75 | 75 | 2 | 20 |
| **Architectural quality** (5-point Likert scale)[3] | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 0 | 3 |
| **Amenity value** (5-point Likert scale)[4] | 4 | 4 | 4 | 4 | 2 | 2 | 2 | 2 | 0 | 3 |

Notes: [1,2] The Indifference threshold [IT] and preference threshold [PT] are elements of the outranking concept and in particular the PROMETHEE method that forms the mathematical basis of PRIMATE. They are defined as follows: if the difference between the performances of two alternatives in the respective criterion is less than the indifference threshold the two alternatives are counted as indifferent, such that none is preferred to the other. If the difference is above the preference threshold the alternative with the better performance is strictly preferred to the other (mathematically it received a score of 1). If the difference is in between, the better alternative is weakly preferred to the other and received a score between 0 and 1, such that the score linearly increases with the difference between the performances (…) (Drechsler 2004: p. 3). [3, 4] 1 – very good, 2 – good, 3 – average, 4 – poor, 5 – very poor.

**Step 5 – Evaluation and Prioritisation**

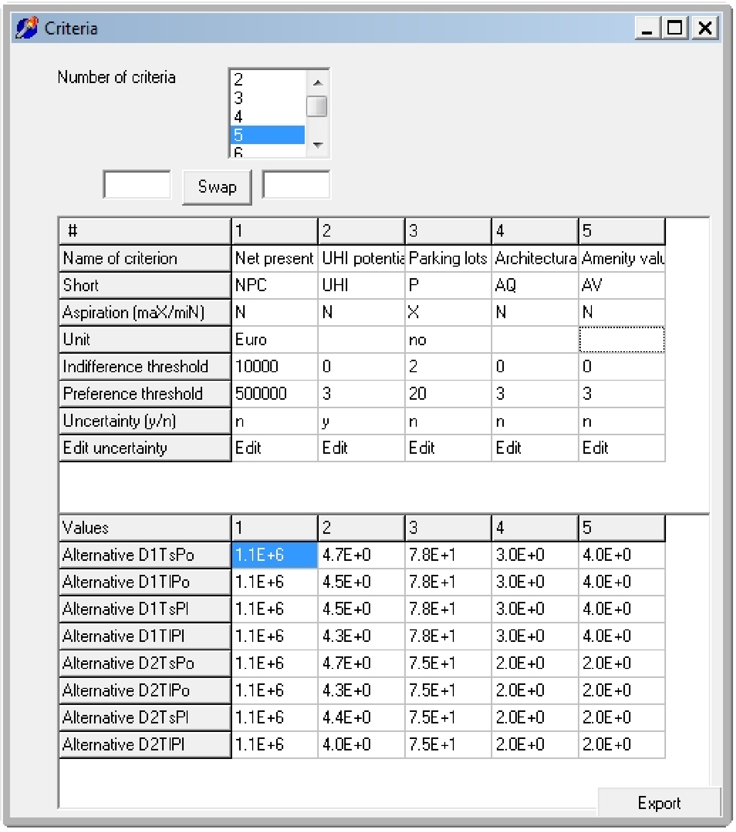
The MCA compares the alternatives described above. This implies that the status quo is due to the main goal of the planning process, i.e. the redevelopment of the area, not considered for the assessment. Nevertheless, it is interesting to examine, how the heat stress levels corresponding to the respective drafts compare with the UHI potential of the status quo for different climatic conditions. Table 6.3-8 gives an overview about the results of this comparison. It can be seen that mainly due to the already existing vegetation the status quo performs quite well under current climatic conditions. The performance gap widens over time, especially regarding the best performing drafts. Furthermore, simulations give evidence that the heat stress level increases substantially due to the changing climatic conditions if the status quo, i.e. the current spatial configuration, does not change. A considerable share of this increase can be avoided if the best performing alternative 8 is implemented.

**Table 6.3-8: Heat stress potentials of the status quo configuration and the alternatives of the Winzerberge project for the periods 1981-2000, 2021-2050, 2071-2100**

| Period | Status quo | Alter-native 1 | Alter-native 2 | Alter-native 3 | Alter-native 4 | Alter-native 5 | Alter-native 6 | Alter-native 7 | Alter-native 8 |
|---|---|---|---|---|---|---|---|---|---|
| **1981-2010** | 1.9 | 2.1 | 2.1 | 1.8 | 1.8 | 1.9 | 2.0 | 1.6 | 1.6 |
| **2021-2050** | | | | | | | | | |
| CMIP5 (RCP 4.5) | 2.9 | 3.0 | 3.0 | 2.8 | 2.7 | 2.9 | 2.8 | 2.6 | 2.5 |
| CMIP5 (RCP 8.5) | 3.3 | 3.5 | 3.4 | 3.2 | 3.1 | 3.3 | 3.2 | 3.0 | 2.9 |
| **2071-2100** | | | | | | | | | |
| CMIP5 (RCP 4.5) | 3.7 | 3.8 | 3.5 | 3.6 | 3.4 | 3.7 | 3.4 | 3.5 | 3.2 |
| CMIP5 (RCP 8.5) | 5.6 | 5.6 | 5.4 | 5.4 | 5.2 | 5.6 | 5.3 | 5.3 | 4.7 |

The application of the MCA approach Stochastic PROMETHEE II is facilitated by using software for Probabilistic Multi-Attribute Evaluation – PRIMATE (Drechsler 2004), which has already been tested in several pilot projects dealing with various aspects of climate change adaptation at the regional and local level. Therefore, the input data of the Winzerberge evaluation (see Table 6.3-7) is entered into and processed with PRIMATE (see Table 6.3-3).

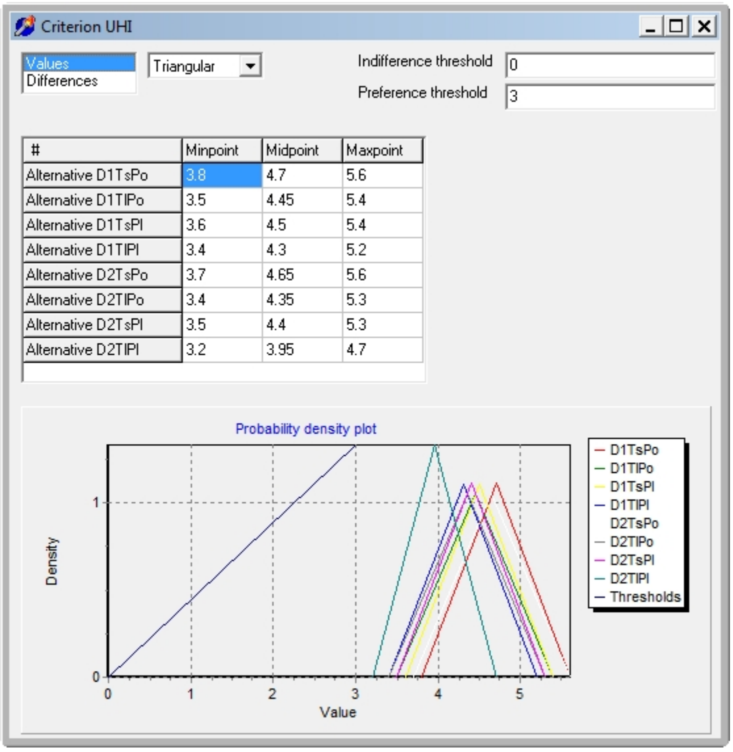
One option for considering uncertainty in criteria values in PRIMATE is through the use of score ranges, triangular or other probability distributions and the application of a Monte Carlo simulation approach. The resulting uncertainty of the final outcomes is documented in PRIMATE (see Figure 6.3-10 and Figure 6.3-11). Uncertainty in the UHI potential scores is due to the use of two RCPs. For the assessment with PRIMATE a triangular distribution is used (see Figure 6.3-9).




| # | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Name of criterion | Net present | UHI potentia | Parking lots | Architectura | Amenity valu |
| Short | NPC | UHI | P | AQ | AV |
| Aspiration (maX/miN) | N | N | X | N | N |
| Unit | Euro | | no | | |
| Indifference threshold | 10000 | 0 | 2 | 0 | 0 |
| Preference threshold | 500000 | 3 | 20 | 3 | 3 |
| Uncertainty (y/n) | n | y | n | n | n |
| Edit uncertainty | Edit | Edit | Edit | Edit | Edit |

| Values | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Alternative D1TsPo | 1.1E+6 | 4.7E+0 | 7.8E+1 | 3.0E+0 | 4.0E+0 |
| Alternative D1TlPo | 1.1E+6 | 4.5E+0 | 7.8E+1 | 3.0E+0 | 4.0E+0 |
| Alternative D1TsPl | 1.1E+6 | 4.5E+0 | 7.8E+1 | 3.0E+0 | 4.0E+0 |
| Alternative D1TlPl | 1.1E+6 | 4.3E+0 | 7.8E+1 | 3.0E+0 | 4.0E+0 |
| Alternative D2TsPo | 1.1E+6 | 4.7E+0 | 7.5E+1 | 2.0E+0 | 2.0E+0 |
| Alternative D2TlPo | 1.1E+6 | 4.3E+0 | 7.5E+1 | 2.0E+0 | 2.0E+0 |
| Alternative D2TsPl | 1.1E+6 | 4.4E+0 | 7.5E+1 | 2.0E+0 | 2.0E+0 |
| Alternative D2TlPl | 1.1E+6 | 4.0E+0 | 7.5E+1 | 2.0E+0 | 2.0E+0 |

**Figure 6.3-8: MCA data matrix in PRIMATE (2071-2100)**




| # | Minpoint | Midpoint | Maxpoint |
|---|---|---|---|
| Alternative D1TsPo | 3.8 | 4.7 | 5.6 |
| Alternative D1TlPo | 3.5 | 4.45 | 5.4 |
| Alternative D1TsPl | 3.6 | 4.5 | 5.4 |
| Alternative D1TlPl | 3.4 | 4.3 | 5.2 |
| Alternative D2TsPo | 3.7 | 4.65 | 5.6 |
| Alternative D2TlPo | 3.4 | 4.35 | 5.3 |
| Alternative D2TsPl | 3.5 | 4.4 | 5.3 |
| Alternative D2TlPl | 3.2 | 3.95 | 4.7 |

**Figure 6.3-9: Entering UHI potential scores in PRIMATE (2071-2100)**

PRIMATE performs 10,000 runs and calculates for each alternative the outflow, i.e. the positive preference flow and extent to which the alternative outranks all other alternatives, the inflow, i.e. the negative preference flow and extent to which the alternative is outranked by all other alternatives and the net flows, i.e. the aggregation of positive and negative preference flows into a net preference flow. On the basis of these net flows a complete order of the alternatives can be established.

Figure 6.3-10 depicts the net flows of all alternatives for the period 2021-2050. The red bars represent the mean values of the net flows determined by 10,000 PRIMATE runs. The higher the net flow the better performs the respective alternative with regard to all evaluation criteria applied. The yellow uncertainty bar represents two standard deviations of the mean value of the net flows, i.e. about 95.4% of the net flows determined fall within this margin.

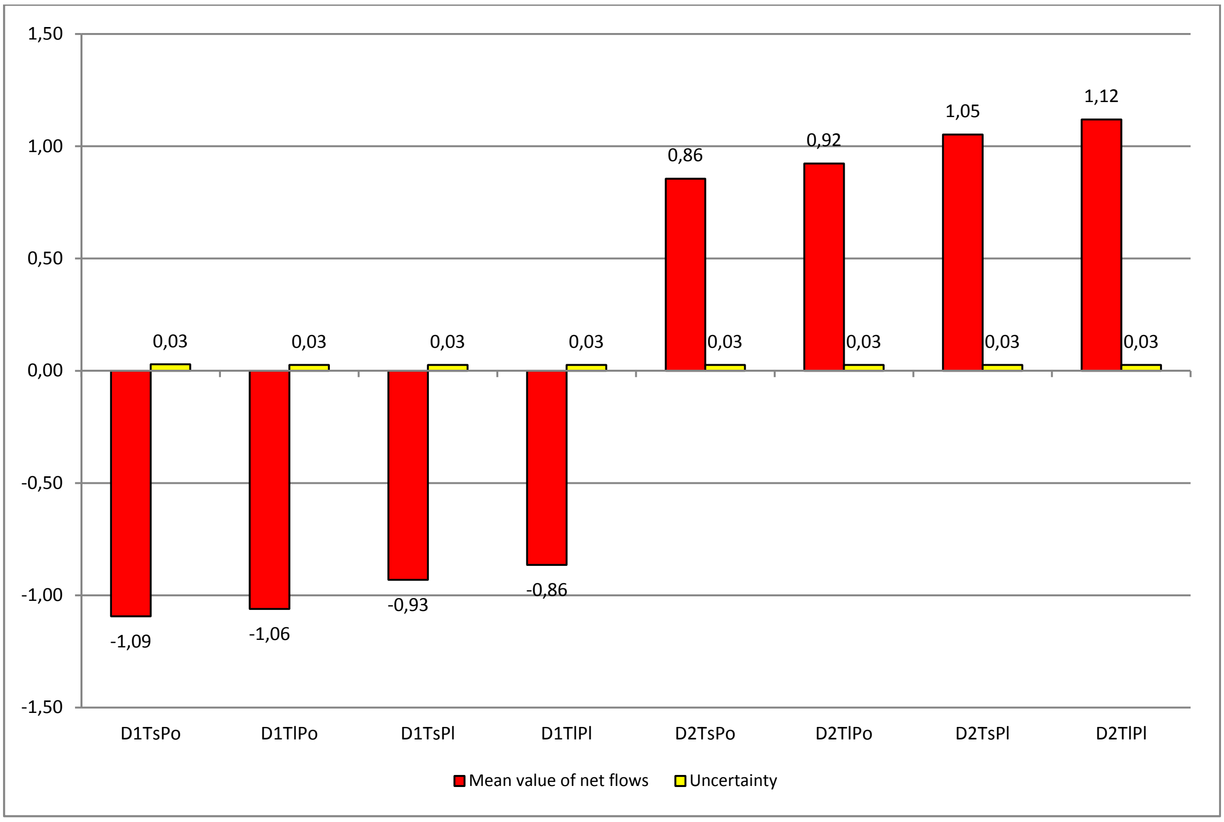



**Figure 6.3-10: Overall net flows of the alternatives for the period 2021-2050**

Note: The uncertainty bar represents two standard deviations of the mean value of the net flows, which means that about 95.4% of the net flows determined by 10,000 PRIMATE runs fall within this margin.

In the medium term perspective all variations of Draft 2 outperform the alternatives based on Draft 1 (Figure 6.3-10). Alternative 8 (D2TlPl: Draft 2, use of large-crowned tree species, light-coloured pavement) ranks best and Alternative 1 (D1TsPo: Draft 1, use of small-crowned tree species, ordinary pavement) shows the worst overall performance. Uncertainty is negligible, i.e. the result is robust.

The results for the long-term perspective are very similar (see Figure 6.3-11). In general it can be noticed that the variations using large-crowned tree species, as some of their beneficial effects only materialise after a certain period of time, perform better than in the long than in the medium term. Again alternative 8 clearly outperforms all other alternatives. The level of uncertainty with regard to these results is higher as the variation of important climatic parameters for RCP 4.5 and RCP 8.5 is more pronounced in the long run. But still the result can be considered to be robust.

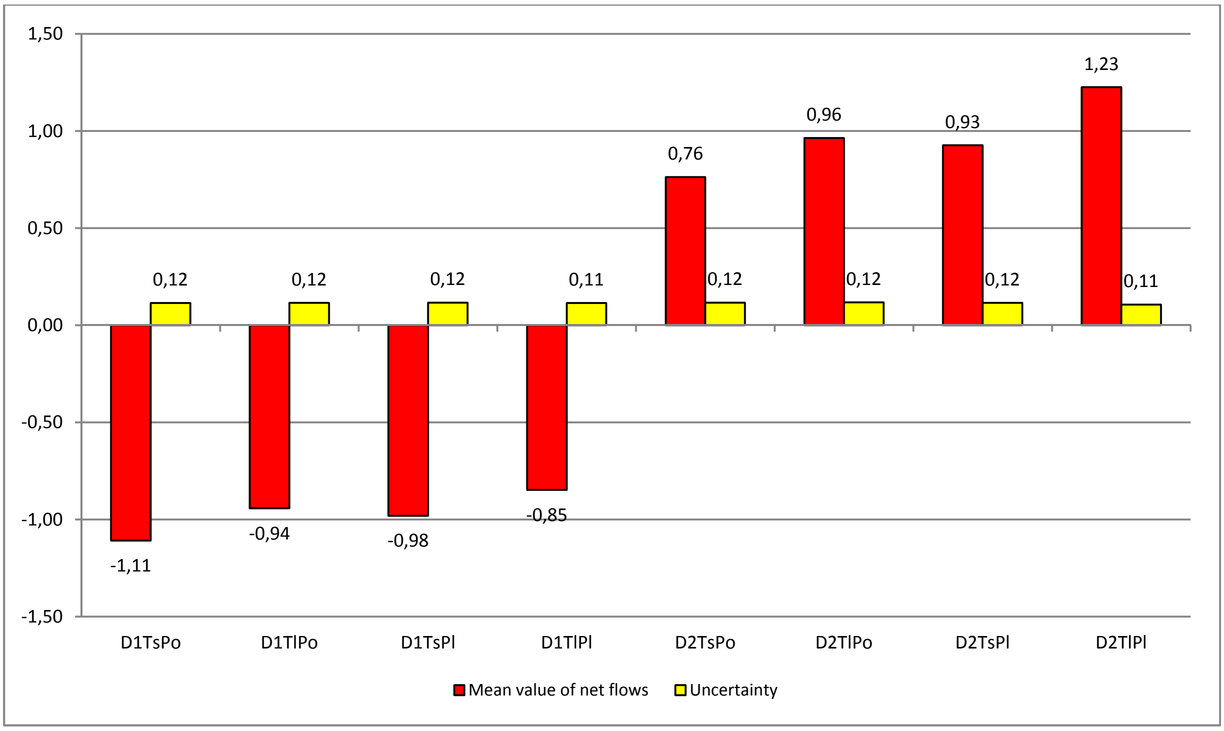



**Figure 6.3-11: Overall net flows of the alternatives for the period 2071-2100**

Note: The uncertainty bar represents two standard deviations of the mean value of the net flows, which means that about 95.4% of the net flows determined by 10,000 PRIMATE runs fall within this margin.

The UHI potential scores for the alternatives vary quite substantially as can be seen in Table 6.3-8. This is been confirmed by the net (preference) flows for this criterion (Figure 6.3-12 and Figure 6.3-13).

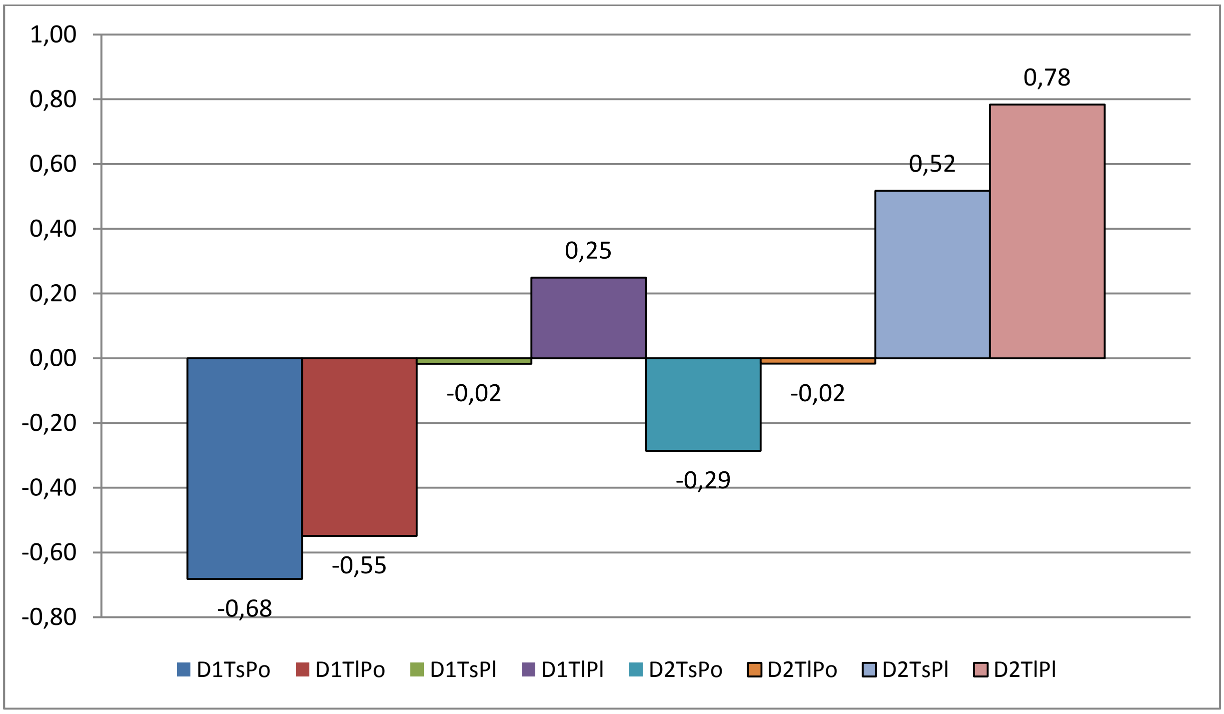



**Figure 6.3-12: UHI potential net flows of the alternatives for the period 2021-2050**

Figure 6.3-12 and Figure 6.3-13 illustrate that not all alternatives based on Draft 2 outperform in this respect the ones being based on Draft 1. In the medium term alternative 4 (D1TlPl: Draft 1, use of large-crowned tree species, light-coloured pavement) ranks third and, thereby, outperforms two variations of Draft 2. As already noticed before, variations of Draft 1 and Draft 2 using large-crowned tree species tap their full potential to mitigate heat stress only after a certain period of time. Their performance regarding the criterion UHI potential improves remarkably in the long run. This can easily be seen, if the net flows of the alternatives 3 (D1TsPl), 4 (D1TlPl), 7 (D2TsPl) and 8 (D2TlPl) for the period 2021-2050 and the period 2071-2100 are compared (see Figure 6.3-10 and Figure 6.3-11).

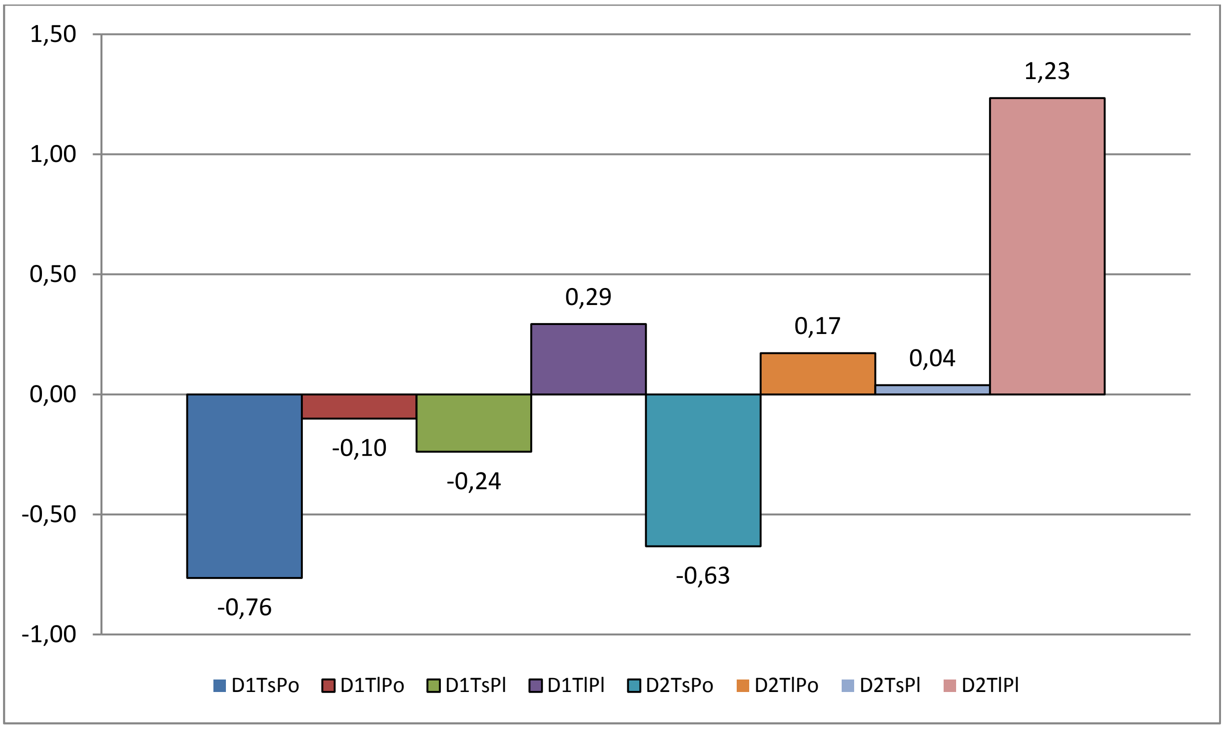



**Figure 6.3-13: UHI potential net flows of the alternatives for the period 2071-2100**

The final result of the assessment can be presented as mean values of the overall net flows (and the corresponding standard deviations) or as a ranking of the alternatives. In the latter case the uncertainty of the result is expressed as a probability of an alternative to rank first, second and so on. Figure 6.3-14 illustrates the ranking of the alternatives for the period 2021-2050 and Figure 6.3-15 for the period 2071-2100.

For the medium term perspective a comparatively unambiguous ranking of the alternatives is been determined. Unsurprisingly, the ranking is in accordance with the order of the net flows for this period. With a probability of 96% alternative 8 (D2TlPl) ranks first. Even though the final result with regard to the best alternative is almost the same in the long term, i.e. with a probability of 91% alternative 8 ranks first, due to the higher level of uncertainty the overall ranking is much more ambiguous for the period 2071-2100. This holds especially for the alternatives 6 (D2TlPo: 2$^{nd}$) and 7 (D2TsPl: 3$^{rd}$) as well as alternative 2 (D1TlPo: 6$^{th}$) and 3 (D1TsPl: 7$^{th}$), which also have changed ranks compared to the medium term perspective.

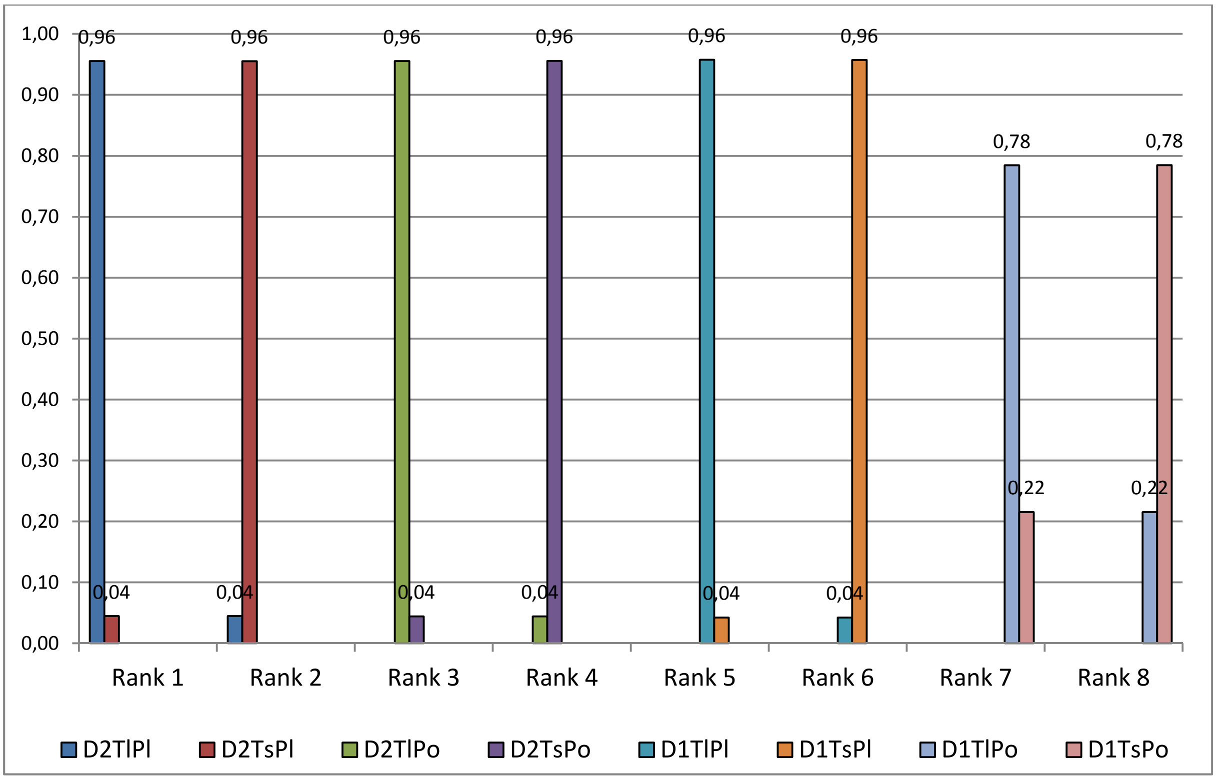



**Figure 6.3-14: Overall ranking of the alternatives for the period 2021-2050**

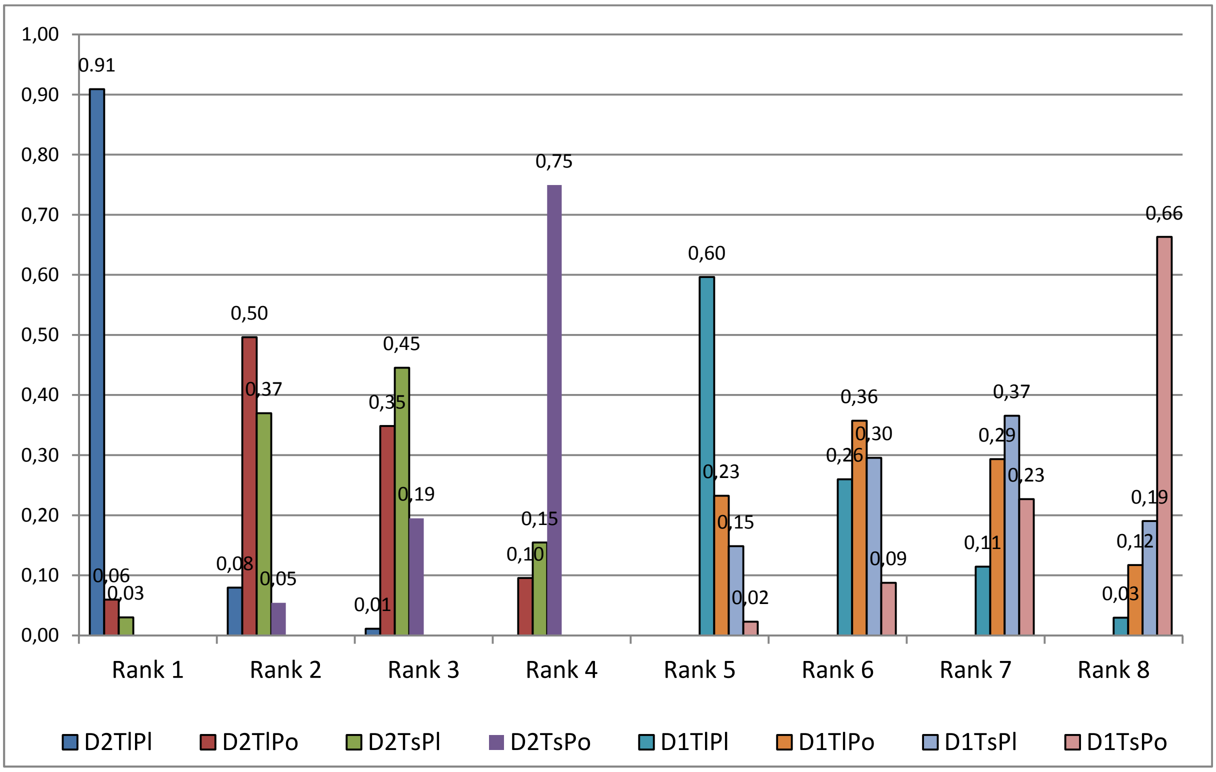



**Figure 6.3-15: Overall ranking of the alternatives for the period 2071-2100**

These are the main results of the multi-criteria assessment for the Winzerberge case study:

- The overall performance of the four variations of Draft 2 is better than the ones being based on Draft 1. Therefore, Draft 2 can be regarded as the superior basic draft.
- Light-coloured pavements as well as large-crowned trees have a beneficial impact on site-specific micro-climatic conditions. In the short and medium term this effect is similar, but as time elapses the positive effect of large-crowned trees continuously increases whereas the benefits of the light-coloured pavements are immediate but static.
- Alternative 8 (D2TlPl: Draft 2, use of large-crowned tree species, light-coloured pavement) outperforms all other alternatives. This holds with a probability of 96% in the medium term and with a probability of 91% also in the long term perspective. The result is statistically robust.

## 6.4 Jena - Redevelopment of the central urban square Inselplatz

Oliver Gebhardt, UFZ

The “Campus Inselplatz” project aims at redeveloping a 3 ha of inner-city greyfield, which is currently used as parking area, into a new campus of the Friedrich Schiller University Jena. In May 2014 a preliminary version of the land development plan for the area has been approved by the city council. The MCA will compare three alternative ways to implement this version of the land development plan. The main decision makers in the process of developing the complex of buildings are the Federal state of Thuringia and the university. The decisions concerning the public area surrounding the buildings are prepared by the Department of City Planning and finally taken by the city council. Still, there are consultations between these three main actors regarding the building structure as well as the public area.

**Figure 6.4-1: Urban square Inselplatz**
Note: Area is marked red.
Source: Landsat Image, Google Earth Pro

**Figure 6.4-2: Model of the future Inselplatz (preliminary)**

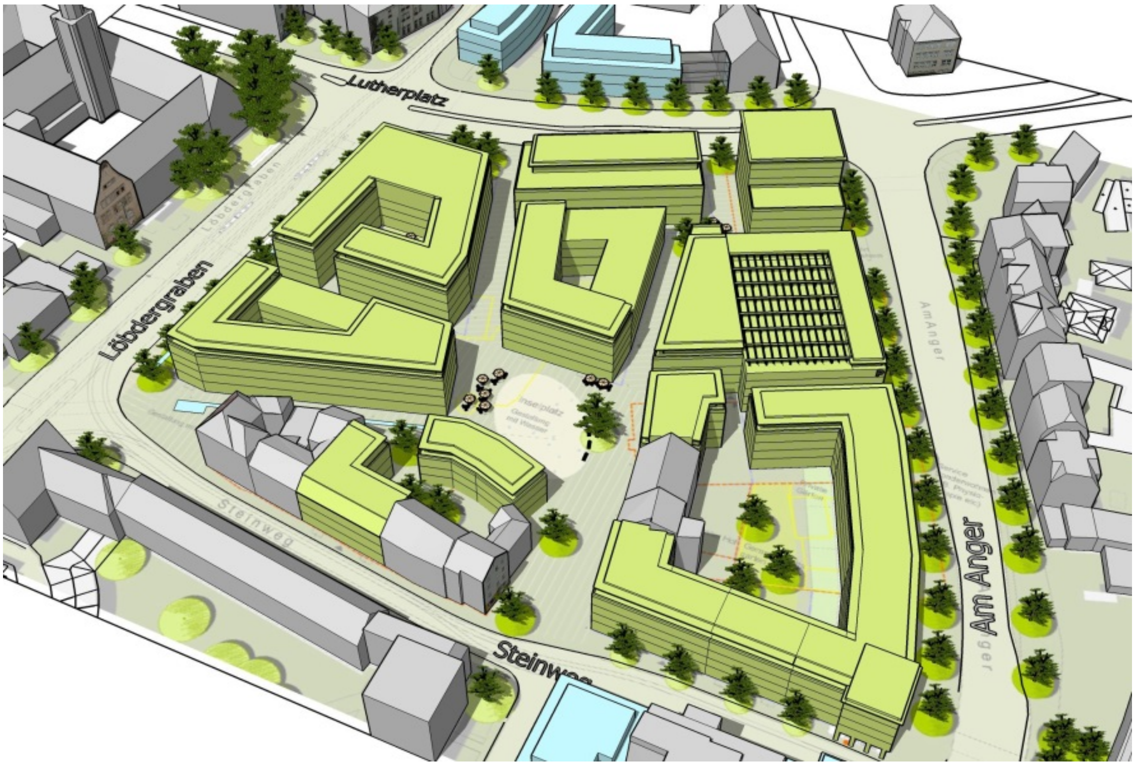



**Figure 6.4-3: 3-D drawing of the future Inselplatz (preliminary)**

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

Jena is surrounded by steep shell limestone slopes, which operate as a thermal storage system making it one of the warmest places in Central Germany. Based on current climate projections an increase of heat stress events can be expected. Until the end of the century the average maximum temperature in summer will increase by 3 K (CMIP5, RCP 4.5) respectively 6 K (CMIP5, RCP 8.5) and the number of hot days will be up to three times (CMIP5, RCP 4.5) respectively four times (CMIP5, RCP 8.5) higher than under current climatic conditions. For the development of key parameters on the basis of different models and scenarios see Table 6.4-1.

**Table 6.4-1: Selected climatic parameters (1981-2010, 2021-2050, 2071-2100)**[37]

| | 1981-2010 | 2021-2050 WETTREG A1B | 2021-2050 STAR A1B | 2021-2050 CMIP5 RCP4.5 | 2021-2050 CMIP5 RCP8.5 | 2071-2100 WETTREG A1B | 2071-2100 CMIP5 RCP4.5 | 2071-2100 CMIP5 RCP8.5 |
|---|---|---|---|---|---|---|---|---|
| $T_{max}$ in summer quarter (°C) | 24 | 26 | 25 | 25.7 | 26.4 | 28 | 27.2 | 30.2 |
| Number of hot days ($T_{max} \geq$ 30°C) | 11 | 19 | 20 | 18 | 22 | 39 | 35 | 49 |
| Precipitation in summer quarter (mm) | 160 | 185 | 170 | * | * | 175 | * | 135 |
| Number of sultry days (vapour pressure > 18,8 hPa) | 2.4 | 8.8 | 4.5 | - | - | 17.8 | - | - |

Note: *Standard deviation of natural variability of the parameter is higher than the signal determined by the model ensemble.

Due to various aspects as the degree of soil sealing, housing density etc. the heat stress potential is comparatively high in the city centre, where the Inselplatz is located. Moreover, a substantial increase of the number and intensity of heat stress events has been projected for the future.

Changes in the site-specific heat stress potential under varying climatic conditions can be simulated using the modelling software Urban Heat Tool - URBAHT. The software uses an algorithm to process data on various structural and climatic factors (see Box 1), which can easily be obtained from public sources.[38] The rough estimates (Urban heat island – UHI potential scores) determined with URBAHT do not compare with those of established software packages for microclimatic modelling, e.g. Predicted Mean Votes determined with ENVI-met, but the tool's low data requests and immediate results facilitate its integration into established planning routines.

The UHI potential scores range from 0 (no heat stress) to 10 (maximum heat stress level) (see Figure 6.3-7).

Table 6.4-2 gives an overview of the results obtained for the current spatial configuration of the Inselplatz, i.e. the heat stress level for the status quo under current and future climatic conditions. Measurement data from the German National Meteorological Service (DWD) and climate projection data from the Coupled Model Intercomparison Project - Phase 5 (CMIP5)[39] for Representative Concentration Pathways (RCP) 4.5 and 8.5 provided by the KNMI Climate Explorer are used for the simulations. The scores indicate that present heat stress level is compared to other Parts of the city rather high and will even increase substantially in future.[40]

[37] STAR (STAtistically based Regional climate model) and WettReg (WEaTher-Type based REGionalisation) are regional climate models, which belong to the empirical statistical downscaling methods. Both models use global climate data from ECHAM5.
[38] For further information see Step 4 – Data collection.
[39] For further Information on CMIP5 see http://cmip-pcmdi.llnl.gov/cmip5/data_getting_started.html
[40] When interpreting the UHI potential scores one has to keep in mind that the scale is identical for all climate zones.

**Table 6.4-2: URBAHT heat stress potential scores of the Inselplatz - status quo**

| Period | Status quo |
|---|---|
| **1981-2010** | 3.7 |
| **2021-2050** | |
| CMIP5 (RCP 4.5) | 4.9 |
| CMIP5 (RCP 8.5) | 5.1 |
| **2071-2100** | |
| CMIP5 (RCP 4.5) | 5.6 |
| CMIP5 (RCP 8.5) | 7.4 |

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

The basis for the MCA is the current version of the land development plan (see Figure 6.4-4).

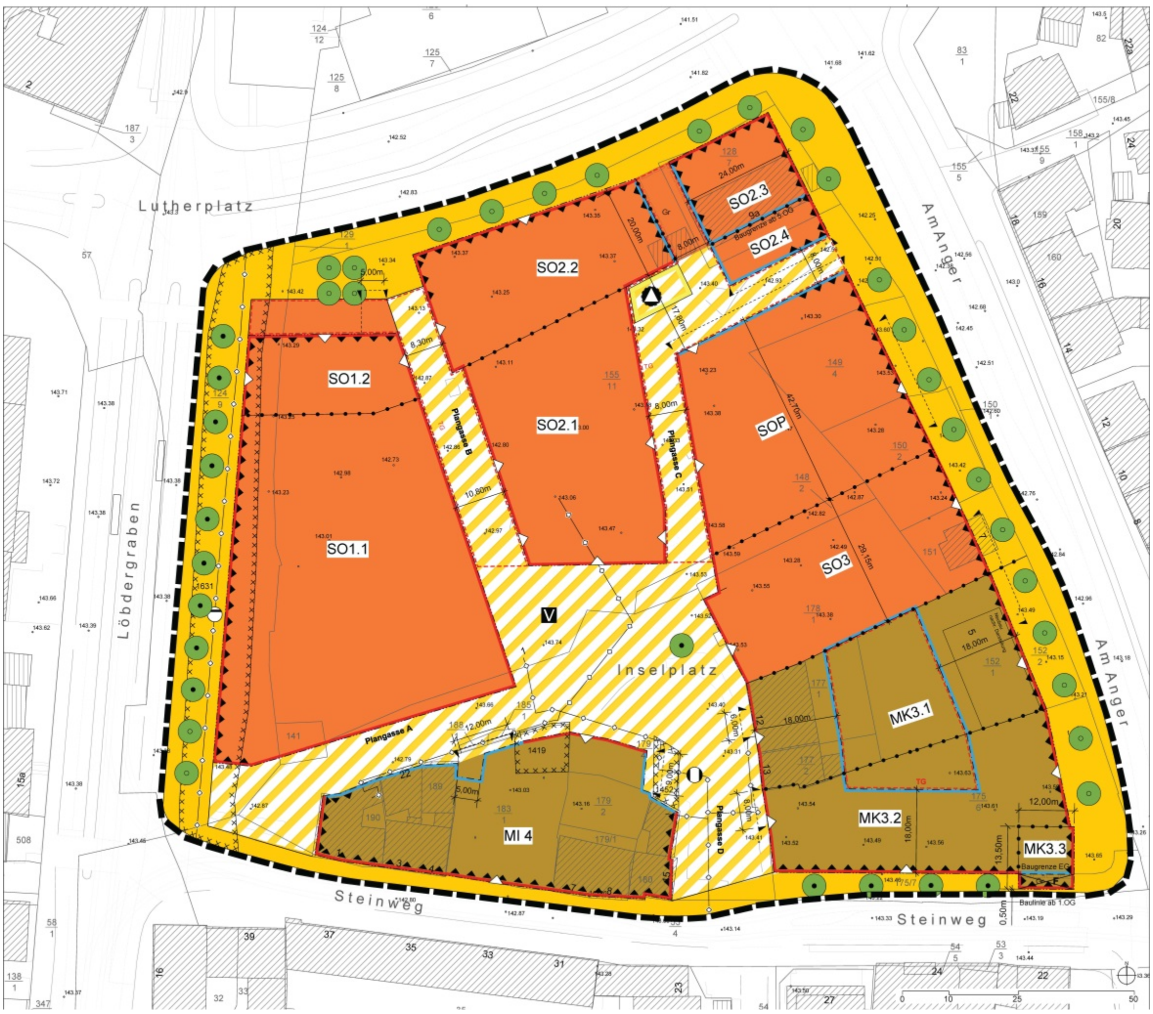



**Figure 6.4-4: Current version of the land development plan Inselplatz**

The variations of the land development plan, which will be compared are described in Table 6.4-3 and visualised in Figure 6.4-5.

**Table 6.4-3: Description of adaptation measures Inselplatz**

| | Alternative 1 | Alternative 2 | Alternative 3 |
|---|---|---|---|
| Number of trees | Existing trees: 14<br>New trees: 25 | Existing trees: 14<br>New trees: 29 | Existing trees: 14<br>New trees: 31 |
| Species of newly planted trees | 25 small-crowned trees | 15 large-crowned trees<br>14 small-crowned trees | 27 large-crowned trees<br>4 small-crowned trees |
| Colour schemes of pavements | Entire area: ordinary pavements | Inner area: light-coloured pavements<br>Outer area: ordinary pavements | Entire area: light-coloured pavements |
| Roof greening of new flat roofs | 69% tar-gravel-roof<br>31% extensive green roof | 48% tar-gravel-roof<br>52% extensive green roof | 30% tar-gravel-roof<br>70% extensive green roof |
| Artificial water course | none | $40m^2$ | $80m^2$ |

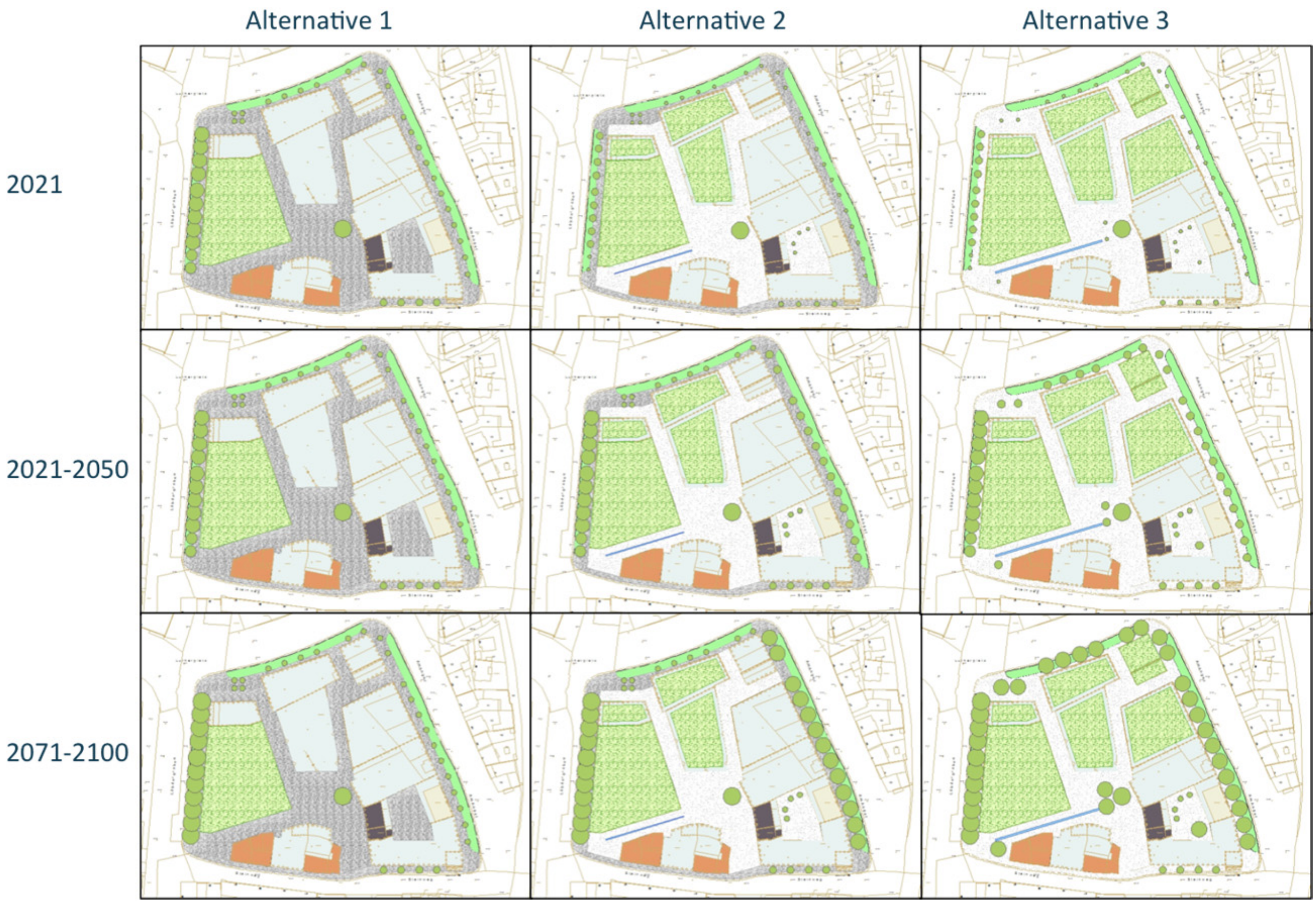



**Figure 6.4-5: Visualisation of the alternatives for the periods: Date of completion, 2021-2050, 2071-2100**

**Step 3 - Evaluation Criteria and Method**

**Step 3a Selection of evaluation criteria**

The following criteria are chosen to compare the alternatives:

**Net present costs** (monetary) consist of the investment costs and the maintenance costs of the green roofs, the pavements and green structures, i.e. lawn and trees, and the investment costs of the artificial water courses for 30 years (period 2021-2050) respectively 80 years (2021-2100). For the green roofs a CBA has been performed considering cost differences, i.e. differences in investment, reinvestment, rehabilitation, maintenance costs, and the private benefits including stormwater fee savings, savings in the installation of stormwater management facilities and energy cost savings. The net present value of the three types of roofs is included in the overall net present costs of the three alternatives. As recommended by national guideline in general, e.g. for calculation of the net present costs of the alternatives for the MCA, a discount rate of 1.5% p.a. is applied.

Additionally, some public benefits, i.e. the value of habitat creation value and carbon sequestration are determined for illustrating at least some of the manifold public benefits of green roofs. As a supplementary information for three types of green roofs, two periods, i.e. 40 years (1 life cycle) and 80 years (two life cycles) and three discount rates, i.e. 1.5%, 3% and 5%, the net present value differences per $m^2$ between a green roof and a tar-and-gravel roof in Jena are calculated.

The **heat stress potential** (quantitative) represents the heat stress level related to the respective alternative. It is determined with the URBAHT tool. For the 80 year-assessment period the average scores of both single 30-year periods have been used. The **architectural quality** of the drafts (qualitative) and the **amenity value** (qualitative) for residents and guests are also considered for the assessment.

**Step 3b Selection of evaluation method(s)**

Several assessment methods accounting differently for various types of uncertainty can be applied to determine the most appropriate alternative. Empirical evidence shows that multi-criteria analysis (MCA) is a promising tool to support such decision processes in the field of climate change adaptation. Multi-attribute decision-making (MADM), a type of MCA, which compares pre-defined sets of alternatives, is often used for applicability reasons. There are MADM concepts, which are based on multi-attribute utility theory (MAUT) and so called outranking concepts, e.g. PROMETHEE, which perform pairwise comparisons of the criteria scores of all alternatives.

In contrast to MAUT approaches outranking concepts do not assume that decision-makers are completely aware of their preference structure. Furthermore, they can deal with uncertain, incomplete, differently scaled and inconsistent data. Applied in the traditional way, e.g. PROMETHEE I, they do not allow for compensation of positive and negative criteria scores. Thereby it is possible to discover unsolvable trade-off between alternatives. As PROMETHEE I provides partial pre-orders of alternatives, in these cases rankings will be incomplete. The advantage of identifying non-comparable measures is that the exchange amongst the different stakeholder-groups about the evaluation criteria and their weighting might be promoted. A complete ranking can be obtained if the so-called positive and negative preference flows are aggregated into net preference flows, which can easily be ordered (PROMETHEE II). If there are uncertainties in the criterion values which shall be considered in terms of score ranges, triangular distributions or any other probability functions Stochastic PROMETHEE II can be applied.

For the Inselplatz project multiple, differently scaled evaluation criteria are used to comparatively assess the alternative drafts. As for the determination of the UHI potential the RCPs 4.5 and 8.5 are used there is uncertainty concerning the performance of the alternatives with regard to this criterion. Therefore, **Stochastic PROMETHEE II** is applied for the assessment.

A CBA is been carried out for the green roofs and the net present values obtained are considered for the calculation of the net present costs of the alternatives.

**Step 3c Weighting of evaluation criteria**

It was expected to consider preference (=weighting) sets of various different stakeholders, e.g. planner, politician, citizen, for the MCA. But it turned out that this does not fit to existing planning routines. In real world urban planning processes in Jena there is formal and informal stakeholder participation. The results of these activities are reflected in the drafting and re-drafting process. So this information is somehow "digested" by the planner and to some extent formally and informally regarded in the planning exercise. Therefore, the planner has to be able to produce a somehow "balanced" weighting set when taking her decisions. Otherwise opposition to the final draft will prevent it to be accepted by the City council. Therefore, planners are very keen on considering all relevant stakeholder interests. For the Inselplatz assessment two planners involved in the planning process elicited the weights individually (see Table 6.4-4). Both weighting sets have been used for the assessment to somehow control for some kind of perception bias.

**Table 6.4-4: Criteria weighting Inselplatz**

| Criteria | Weights in % | |
|---|---|---|
| | Urban Planner 1 | Urban Planner 2 |
| Heat stress potential | 35 | 20 |
| Costs | 20 | 40 |
| Amenity value | 20 | 20 |
| Architectural quality | 25 | 20 |

**Step 4 – Data collection**

The data used for the MCA comes from different sources. **Investment cost** data is provided by the Department of City Planning, private planning consultancies, private engineering offices, construction material companies and comes from literature. **Maintenance costs** of the tree population are supplied by the municipal service company KSJ, which is responsible for taking care of the green structures on public premises in Jena. The locational **heat stress potential** (UHI potential) unfolding, if drafts are implemented, is estimated using the modelling software Urban Heat Tool – URBAHT (see Box 1). The data on the structural parameters is determined on the basis of existing plans. The climatic data for applying URBAHT comes from two sources. Measurement data is provided by the German National Meteorological Service (DWD). Climate projection data is been sourced from the KNMI Climate Explorer. Information on the alternatives' performances concerning the criteria **architectural quality** and **amenity value** is collected through expert judgments of local planners.

Table 6.4-5 and Table 6.4-6 give an overview of the data used.

**Table 6.4-5: Heat stress potentials of alternatives at Inselplatz for the periods 1981-2010, 2021-2050, 2071-2100**

| Period | Alternative 1 | | | Alternative 2 | | | Alternative 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| **1981-2010** | | 4.8 | | | 4.5 | | | 4.1 | |
| **2021-2050** | | | | | | | | | |
| CMIP5 (RCP 4.5) | | 5.8 | | | 5.5 | | | 5.0 | |
| CMIP5 (RCP 8.5) | | 6.2 | | | 5.9 | | | 5.4 | |
| **2071-2100** | | | | | | | | | |
| CMIP5 (RCP 4.5) | | 6.6 | | | 6.3 | | | 5.8 | |
| CMIP5 (RCP 8.5) | | 8.4 | | | 8.1 | | | 7.6 | |
| **Minimum, mean, maximum value** | **Min** | **MV** | **Max** | **Min** | **MV** | **Max** | **Min** | **MV** | **Max** |
| Period 2021-2050 | 5.8 | 6 | 6.2 | 5.5 | 5.7 | 5.9 | 5 | 5.2 | 5.4 |
| Period 2071-2100 | 6.6 | 7.5 | 8.4 | 6.3 | 7.2 | 8.1 | 5.8 | 6.7 | 7.6 |

**Table 6.4-6: Data matrix Inselplatz**

| Criteria | Alternative 1 | | | Alternative 2 | | | Alternative 3 | | | IT[1] | PT[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | MV | Max | Min | MV | Max | Min | MV | Max | | |
| **Heat stress potential** (2021-2050) | 5.80 | 6.00 | 6.20 | 5.50 | 5.70 | 5.90 | 5.00 | 5.20 | 5.40 | 0 | 3 |
| **Heat stress potential** (2021-2100) | 6.20 | 6.75 | 7.30 | 5.90 | 6.45 | 7.00 | 5.40 | 5.95 | 6.50 | 0 | 3 |
| **Net present costs** (2021-2050) | 3,714,943 | 3,873,193 | 4,031,442 | 3,744,464 | 3,910,694 | 4,076,924 | 3,735,255 | 3,908,419 | 4,081,583 | 10,000 | 300,000 |
| **Net present costs** (2021-2100) | 4,000,833 | 4,168,875 | 4,336,917 | 4,044,263 | 4,227,042 | 4,409,822 | 4,046,361 | 4,241,971 | 4,437,582 | 10,000 | 300,000 |
| **Amenity value** (2021-2050) (5-point Likert scale)[4] | 3 | 3.25 | 3.5 | 2 | 2.5 | 3 | 1 | 1.5 | 2 | 0 | 3 |
| **Amenity value** (2021-2100) (5-point Likert scale)[4] | 3.25 | 3.375 | 3.5 | 2.25 | 2.5 | 2.75 | 1.25 | 1.5 | 1.75 | 0 | 3 |
| **Architectural quality** (2021-2050) (5-point Likert scale)[3] | 3 | 3.5 | 4 | 2 | 2.5 | 3 | 1 | 1.5 | 2 | 0 | 3 |
| **Architectural quality** (2021-2100) (5-point Likert scale)[3] | 3.25 | 3.625 | 4 | 2.25 | 2.625 | 3 | 1.25 | 1.625 | 2 | 0 | 3 |

Notes: [1,2] The Indifference threshold [IT] and preference threshold [PT] are elements of the outranking concept and in particular the PROMETHEE method that forms the mathematical basis of PRIMATE. They are defined as follows: if the difference between the performances of two alternatives in the respective criterion is less than the indifference threshold the two alternatives are counted as indifferent, such that none is preferred to the other. If the difference is above the preference threshold the alternative with the better performance is strictly preferred to the other (mathematically it received a score of 1). If the difference is in between, the better alternative is weakly preferred to the other and received a score between 0 and 1, such that the score linearly increases with the difference between the performances (…) (Drechsler 2004: p. 3). [3, 4] 1 – very good, 2 – good, 3 – average, 4 – poor, 5 – very poor.

**Step 5 – Evaluation and Prioritisation**

Figure 6.4-6 depicts the net flows of all alternatives for the period 2021-2050. The red bars represent the mean values of the net flows determined by 10,000 PRIMATE runs. The higher the net flow the better performs the respective alternative with regard to all evaluation criteria applied. The yellow uncertainty bar represents two standard deviations of the mean value of the net flows, i.e. about 95.4% of the net flows determined fall within this margin.

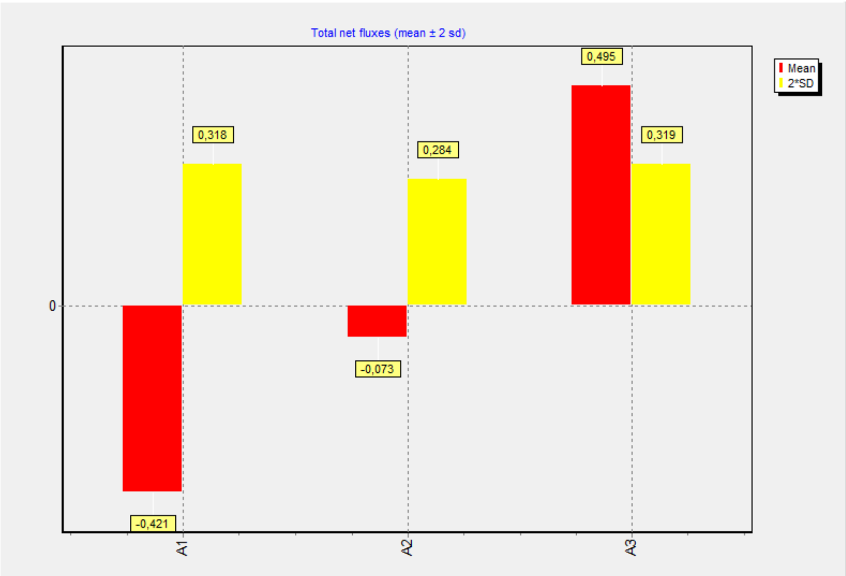



**Figure 6.4-6: Overall net flows of the alternatives for the period 2021-2050**

Note: The uncertainty bar represents two standard deviations of the mean value of the net flows, which means that about 95.4% of the net flows determined by 10,000 PRIMATE runs fall within this margin.

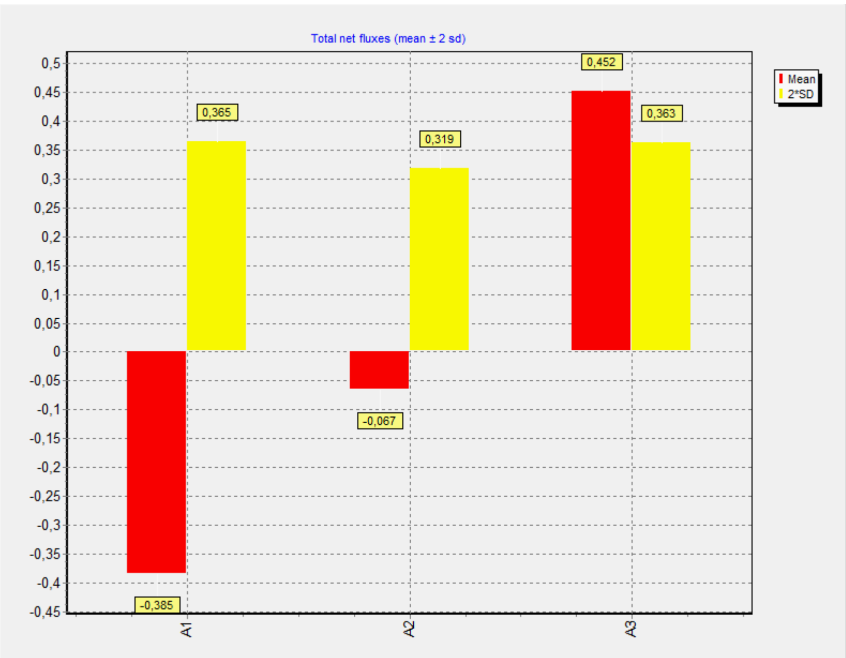



**Figure 6.4-7: Overall net flows of the alternatives for the period 2071-2100**

Note: The uncertainty bar represents two standard deviations of the mean value of the net flows, which means that about 95.4% of the net flows determined by 10,000 PRIMATE runs fall within this margin.

In the medium term as well as in the long-term Alternative 3 outperforms the other options. The level of uncertainty increases in time as the variation of important climatic parameters for RCP 4.5 and RCP 8.5 is more pronounced in the long run.

The heat stress potential scores for the three alternatives vary quite substantially as indicated by the net flows of the criterion heat stress potential (HSP) in Figure 6.4-8 and Figure 6.4-9. Alternative 3 also performs best in this regard.

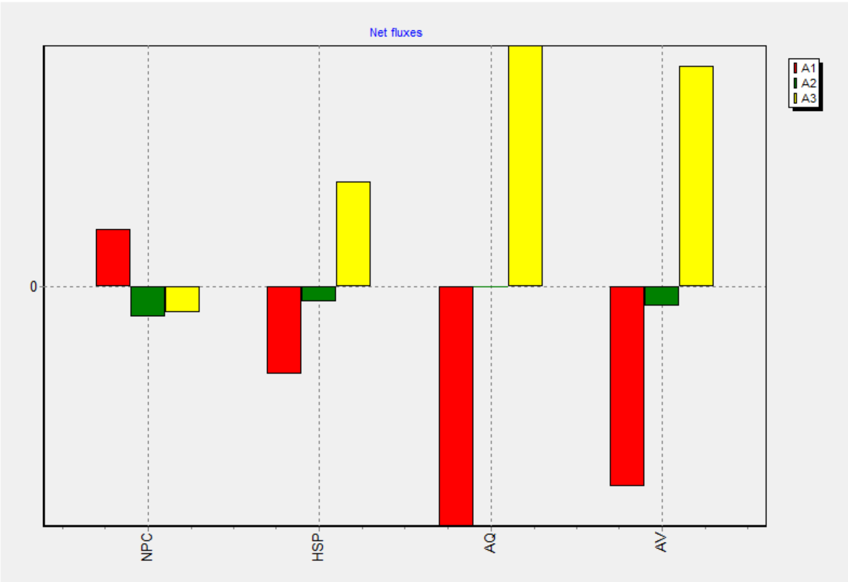



**Figure 6.4-8: Net flows by criterion for 2021-2050**
Notes: Alternative 1 – red bar, Alternative 2 – green bar, Alternative 3 – yellow bar; NPC – net present costs, HSP – heat stress potential, AQ – architectural quality, AV – amenity value.

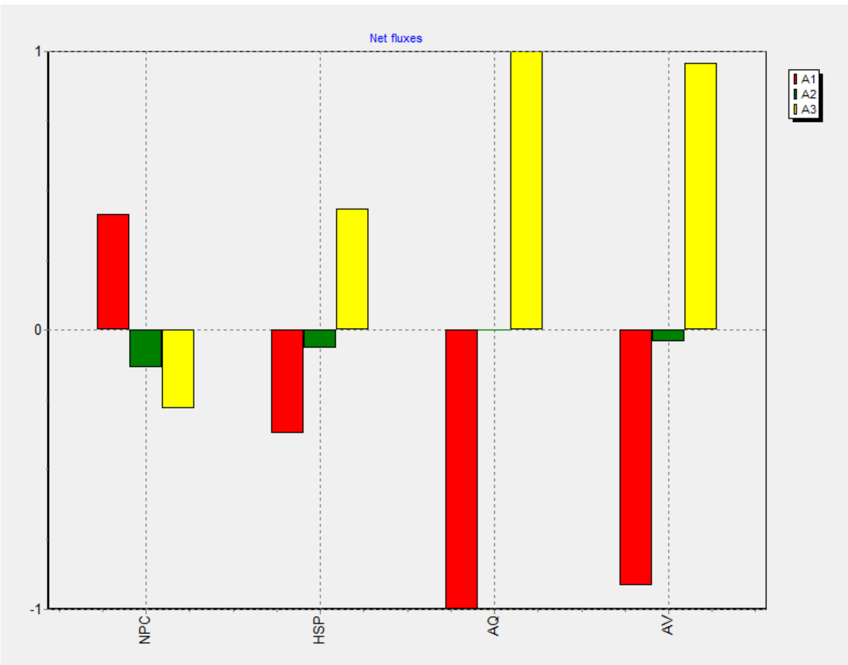



**Figure 6.4-9: Net flows by criterion for 2071-2100**
Notes: Alternative 1 – red bar, Alternative 2 – green bar, Alternative 3 – yellow bar; NPC – net present costs, HSP – heat stress potential, AQ – architectural quality, AV – amenity value.

The final result of the assessment can be presented as mean values of the overall net flows (and the corresponding standard deviations) or as a ranking of the alternatives. In the latter case the uncertainty of the result is expressed as a probability of an alternative to rank first, second and so on. Figure 6.4-10 illustrates the ranking of the alternatives for the period 2021-2050 and Figure 6.4-11 for the period 2071-2100. Unsurprisingly, the rankings are in accordance with the order of the net flows. With a probability of 97.4% respectively 94.6% Alternative 3 ranks first.

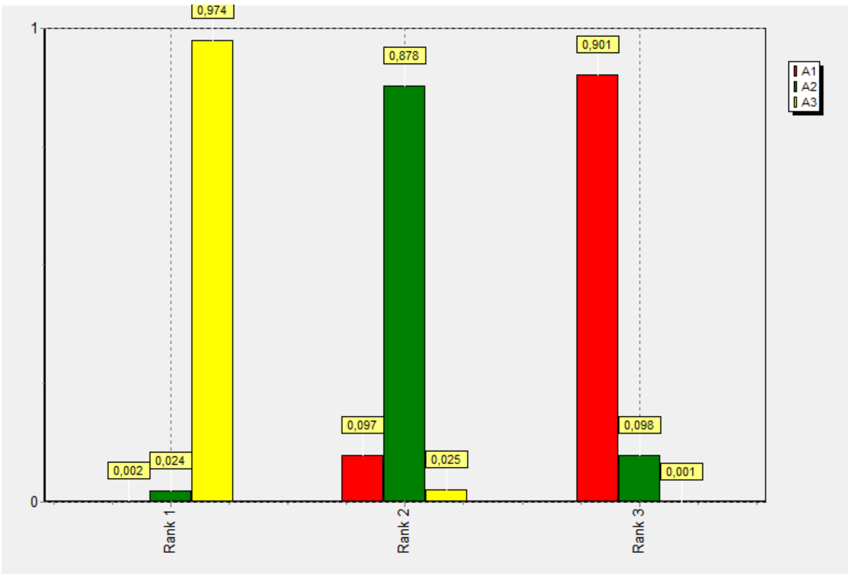



**Figure 6.4-10: Overall ranking of the alternatives for the period 2021-2050**
Notes: Alternative 1 – red bar, Alternative 2 – green bar, Alternative 3 – yellow bar

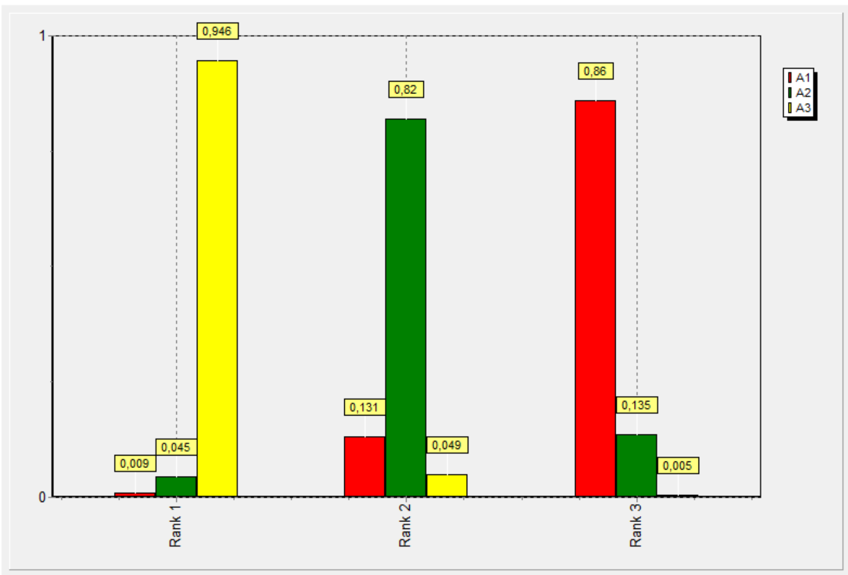



**Figure 6.4-11: Overall ranking of the alternatives for the period 2071-2100**
Notes: Alternative 1 – red bar, Alternative 2 – green bar, Alternative 3 – yellow bar

These are the main results of the multi-criteria assessment for the Inselplatz project:

- Alternative 3 ranks first, alternative 2 second and alternative 1 third in the medium-term (2021-2050) as well as in the long-term perspective (2021-2100).
- In the medium-term perspective the respective probabilities are 97% of alternative 3 ranking first, 88% of alternative 2 ranking second and 90% of alternative 1 ranking third. In the long-term perspective the respective probabilities are 95% of alternative 3 ranking first, 82% of alternative 2 ranking second and 86% of alternative 1 ranking third.
- Results are statistically significant.
- Light-coloured pavements and large-crowned trees have a beneficial impact on site-specific micro-climatic conditions. The (presumably) higher costs also pay-off with regard to the criteria amenity value and architectural quality.
- When comparing the net present costs of a small-crowned and a large-crowned tree over a longer period, e.g. 82 years, regarding tree procurement, planting, replanting and care costs using a 1.5 % discount rate these costs add up to 2,254 EUR for small-crowned tree and 2,121 EUR for large-crowned tree. Furthermore, the latter has a much more beneficial impact on site-specific microclimate.
- The influence of an artificial water course is more ambiguous as it is quite costly and has – due to its dimension – only a limited impact on the microclimate. Its overall value largely depends on how it is assessed with regard to its influence on criteria as amenity value and architectural quality.
- The use of green roofs has a positive impact on the incurring costs when using the discount rate recommended by German authorities, i.e. 1.5%.

**Cost-benefit analysis green roofs**

The net present costs of the three alternatives, i.e. bundles of adaptation measures, have to include the net costs of the three types of green roofs, which are likely to be implemented. Therefore, a cost-benefit analysis is carried out for the three green roof covers. The CBA includes cost differences, i.e. differences in investment, reinvestment, rehabilitation, maintenance costs, and (private) benefits including stormwater fee savings, savings in the installation of stormwater management facilities and energy cost savings. In addition to these (private) cost and benefit figures which have been considered for the MCA, the habitat creation and carbon sequestration value of the green roof covers are calculated. As recommended by national guideline a discount rate of 1.5% p.a. is applied. For sensitivity analysis discount rates of 3% and 5% are used.

The following assumptions are made based on a review of roof greening guidelines, scientific literature and the specific situation in Jena:

- Assessment periods: 40 years
- Roof characteristics: Flat roof
- Investment costs: [41]
    - Extensive green roof cover: 25 EUR/$m^2$, 30 EUR/$m^2$, 35 EUR/$m^2$
    - Tar-and-gravel roof cover: 10 EUR/$m^2$
- Maintenance costs:
    - Extensive green roof: 1 EUR/$m^2$ p.a. (1st year), 0.5 EUR/$m^2$ p.a. (following years)
    - Tar-and-gravel roof: 0.2 EUR/$m^2$ p.a.
- Rehabilitation costs (removal, sealing):
    - Extensive green roof: 55 EUR/$m^2$ (end of 40th year)
    - Tar-and-gravel roof: 45 EUR/$m^2$ (end of 20th year), 35 EUR/$m^2$ (end of 40th year)
- Stormwater fee:[42]
    - Stormwater fee in Jena (2013): 0.72 EUR/$m^2$
    - Run-off coefficient green roof: 0.4
    - Stormwater fee costs extensive green roof: 0.29 EUR/$m^2$ p.a.
    - Stormwater fee costs tar-and-gravel roof: 0.72 EUR/$m^2$ p.a.
- Savings from reduced size of installation of stormwater management facilities
    - One-time benefit of 30% of the investment costs of green roof (City of Portland 2008)
    - 7.50 / 9 / 10.50 EUR/$m^2$
- Energy cost savings
    - 0.25 EUR/$m^2$ p.a.[43] (Mann 2005 based on Hämmerle 1995, Kolb 1997)
- Habitat creation value[44] (City of Portland 2008):
    - 10% of average costs to create and maintain ecological compensation area in Jena
    - 0.035 EUR/$m^2$ p.a. (40 years, 1.5%)

[41] All cost figures are based on Ansel, W.; Baumgarten, H.; Dickhaut. W.; Kruse, E.; Meier, R. (eds.) (2011): Leitfaden Dachbegrünung für Kommunen. Nutzen – Fördermöglichkeiten – Praxisbeispiele. Nürtingen.

[42] § 14a Beitrags- und Gebührensatzung zur Entwässerungssatzung - BGS-EWS des Zweckverbandes „JenaWasser“ (2013)

[43] Mann, Gunter (2005): Ansätze zur objektbezogenen Kosten-Nutzen-Analyse, Stadt und Grün / Das Gartenamt Jg.: 54, Nr.10.

[44] City of Portland, Bureau of Environmental Services (2008): Cost Benefit Evaluation of Ecoroofs. Portland.

- Carbon sequestration:
  - 1.25 kg $C/m^2$ p.a.[45] (Leigh et al. 2014), social costs of carbon: 35 USD/t $CO_2$ (26 EUR /t $CO_2$)
  - 0.033 EUR/$m^2$ p.a.

The three alternatives compared assume green roofs of different sizes (see Table 6.4-3). The size of the green roof covers has an important impact on the overall costs of the roof covers, i.e. the green roof part and the tar-gravel part of the roof cover. Overall roof cover costs for the three alternatives are presented in Table 6.4-7 and Table 6.4–8.

**Table 6.4-7: Overall costs of roof covers: 2021-2050**

| 2021-2050, 1.5% | | Min | MV | Max |
|---|---|---|---|---|
| Alternative 1 | Net present costs roof cover in EUR | 1,032,986 | 1,050,750 | 1,068,513 |
| | Net present benefits green roof cover in EUR | 53,609 | 58,938 | 64,267 |
| | **Overall net present costs roof cover in EUR** | **979,378** | **991,812** | **1,004,246** |
| Alternative 2 | Net present costs roof cover in EUR | 1,014,056 | 1,044,077 | 1,074,099 |
| | Net present benefits green roof cover in EUR | 90,609 | 99,616 | 108,622 |
| | **Overall net present costs roof cover in EUR** | **923,447** | **944,462** | **965,477** |
| Alternative 3 | Net present costs roof cover in EUR | 997,534 | 1,038,254 | 1,078,973 |
| | Net present benefits green roof cover in EUR | 122901.626 | 135117.493 | 147,333 |
| | **Overall net present costs roof cover in EUR** | **874,633** | **903,136** | **931,640** |

**Table 6.4-8: Overall costs of roof covers: 2021-2100**

| 2021-2100, 1.5% | | Min | MV | Max |
|---|---|---|---|---|
| Alternative 1 | Net present costs roof cover in EUR | 1,182,021 | 1,209,576 | 1,237,132 |
| | Net present benefits green roof cover in EUR | 58,191 | 63,520 | 68,849 |
| | **Overall net present costs roof cover in EUR** | **1,123,830** | **1,146,056** | **1,168,283** |
| Alternative 2 | Net present costs roof cover in EUR | 1,183,362 | 1,229,933 | 1,276,504 |
| | Net present benefits green roof cover in EUR | 98,355 | 107,361 | 116,367 |
| | **Overall net present costs roof cover in EUR** | **1,085,008** | **1,122,572** | **1,160,137** |
| Alternative 3 | Net present costs roof cover in EUR | 1,184,533 | 1,247,700 | 1,310,867 |
| | Net present benefits green roof cover in EUR | 133,408 | 145,623 | 157,839 |
| | **Overall net present costs roof cover in EUR** | **1,051,126** | **1,102,077** | **1,153,027** |

It turns out that the bigger the green roof the lower the overall roof cover costs of the respective alternative.

A comparison of the net present values (40 years, 1.5%, 3% and 5%, only private benefits) of 1 $m^2$ of an extensive green roof compared to 1 $m^2$ of a tar-gravel roof leads to the following results:

- Consideration of cost differences and stormwater fee savings of an extensive green roof cover compared to a tar-gravel roof cover savings add up to 0.07 to 0.32 EUR/$m^2$ p.a. (40 years, 1.5%, most / least expensive green roof type).
- Consideration of additional (private) benefits, i.e. private stormwater management savings, energy cost savings further improves the results in favour of the green roof cover. Savings then add up to 0.52 to 0.70 EUR/$m^2$ p.a. (40 years, 1.5%, most / least expensive green roof type).
- Higher discount rates reduce the overall savings. When applying a 5% discount rate and only considering cost differences and stormwater fee savings additional costs for a green roof cover of 0.18 EUR/$m^2$ p.a. accrue. For details see

[45] Leigh et al. (2014): Quantifying carbon sequestration of various green roof and ornamental landscape systems, Landscape and Urban Planning, 123, p.41-48.

- Public benefits are rather low compared to private benefits, i.e. the annual value of the habitat created and carbon sequestered are about 0.03 EUR/m² each (40 years). In absolute terms the habitat creation value is 1.39 EUR/m², i.e. 4,941 EUR for alternative 1, 8,351 EUR for alternative 2, 11,327 EUR for alternative 3. The value of the carbon sequestered by the green roof covers in absolute terms adds up to 116 EUR p.a. for alternative 1, 197 EUR p.a. for alternative 2, 267 EUR p.a. for alternative 3.

The reference option is a tar-gravel roof. Green market cells indicate that the respective type of green roof cover is more efficient than the tar-gravel roof.

- Using the officially recommended discount rate all green roof covers are efficient from a minimum-benefit (cost differences & stormwater fee savings) and from a maximum-benefit (cost differences & stormwater fee savings & private stormwater management & energy savings) perspective (see Table 6.4-9).
- Using a 3% discount rate only the most expensive type of green roof cover is not efficient from a minimum-benefit perspective (see Table 6.4-10).
- Using a 5% discount rate only the least costly type of green roof cover is efficient from a minimum-benefit perspective. From a maximum-benefit perspective all green roof covers are efficient (see Table 6.4 11).

**Table 6.4-9: Comparison three green roof cover types and tar-gravel roof, 40 years, discount rate 1.5%**

| | Extensive green roof cover (25 EUR/m²) | Extensive green roof cover (30 EUR/m²) | Extensive green roof cover (35 EUR/m²) | Tar-gravel roof cover (10 EUR/m²) |
|---|---|---|---|---|
| NPC (cost differences, stormwater fee savings) | 80.20 | 85.20 | 90.20 | 92.95 |
| NPB (private stormwater management & energy savings) | 15.09 | 16.59 | 18.09 | |
| NPV | 65.11 | 68.61 | 72.11 | 92.95 |
| Differences in NPV of green roof and tar-gravel-roof per m² | 27.84 | 24.34 | 20.84 | |
| **Differences in NPV of green roof and tar-gravel-roof per m² p.a.** | **0.70** | **0.61** | **0.52** | |
| | | | | |
| NPC (cost differences, stormwater fee savings) | 80.20 | 85.20 | 90.20 | 92.95 |
| NPB (energy savings) | 7.59 | 7.59 | 7.59 | |
| NPV | 72.61 | 77.61 | 82.61 | 92.95 |
| Differences in NPV of green roof and tar-gravel-roof per m² | 20.34 | 15.34 | 10.34 | |
| **Differences in NPV of green roof and tar-gravel-roof per m² p.a.** | **0.51** | **0.38** | **0.26** | |
| | | | | |
| NPC (cost differences, stormwater fee savings) | 80.20 | 85.20 | 90.20 | 92.95 |
| Differences in NPV of green roof and tar-gravel-roof per m² | 12.75 | 7.75 | 2.75 | |
| **Differences in NPV of green roof and tar-gravel-roof per m² p.a.** | **0.32** | **0.19** | **0.07** | |

**Table 6.4-10: Comparison three green roof cover types and tar-gravel roof, 40 years, discount rate 3%**

| | Extensive green roof cover (25 EUR/m²) | Extensive green roof cover (30 EUR/m²) | Extensive green roof cover (35 EUR/m²) | Tar-gravel roof cover (10 EUR/m²) |
|---|---|---|---|---|
| NPC (cost differences, stormwater fee savings) | 61.63 | 66.63 | 71.63 | 69.81 |
| NPB (private stormwater management & energy savings) | 13.45 | 14.95 | 16.45 | |
| NPV | 48.18 | 51.68 | 55.18 | 69.81 |
| Differences in NPV of green roof and tar-gravel-roof per $m^2$ | 21.63 | 18.13 | 14.63 | |
| **Differences in NPV of green roof and tar-gravel-roof per $m^2$ p.a.** | **0.54** | **0.45** | **0.37** | |
| NPC (cost differences, stormwater fee savings) | 61.63 | 66.63 | 71.63 | 69.81 |
| NPB (energy savings) | 5.95 | 5.95 | 5.95 | |
| NPV | 55.68 | 60.68 | 65.68 | 69.81 |
| Differences in NPV of green roof and tar-gravel-roof per $m^2$ | 14.13 | 9.13 | 4.13 | |
| **Differences in NPV of green roof and tar-gravel-roof per $m^2$ p.a.** | **0.35** | **0.23** | **0.10** | |
| NPC (cost differences, stormwater fee savings) | 61.63 | 66.63 | 71.63 | 69.81 |
| Differences in NPV of green roof and tar-gravel-roof per $m^2$ | 8.18 | 3.18 | -1.82 | |
| **Differences in NPV of green roof and tar-gravel-roof per $m^2$ p.a.** | **0.20** | **0.08** | **-0.05** | |

**Table 6.4-11: Comparison three green roof cover types and tar-gravel roof, 40 years, discount rate 5%**

| | Extensive green roof cover (25 EUR/m²) | Extensive green roof cover (30 EUR/m²) | Extensive green roof cover (35 EUR/m²) | Tar-gravel roof cover (10 EUR/m²) |
|---|---|---|---|---|
| NPC (cost differences, stormwater fee savings) | 47.90 | 52.90 | 57.90 | 50.50 |
| NPB (private stormwater management & energy savings) | 12.00 | 13.50 | 15.00 | |
| NPV | 35.90 | 39.40 | 42.90 | 50.50 |
| Differences in NPV of green roof and tar-gravel-roof per $m^2$ | 14.61 | 11.11 | 7.61 | |
| **Differences in NPV of green roof and tar-gravel-roof per $m^2$ p.a.** | **0.37** | **0.28** | **0.19** | |
| NPC (cost differences, stormwater fee savings) | 47.90 | 52.90 | 57.90 | 50.50 |
| NPB (energy savings) | 4.50 | 4.50 | 4.50 | |
| NPV | 43.40 | 48.40 | 53.40 | 50.50 |
| Differences in NPV of green roof and tar-gravel-roof per $m^2$ | 7.11 | 2.11 | -2.89 | |
| **Differences in NPV of green roof and tar-gravel-roof per $m^2$ p.a.** | **0.18** | **0.05** | **-0.07** | |
| NPC (cost differences, stormwater fee savings) | 47.90 | 52.90 | 57.90 | 50.50 |
| Differences in NPV of green roof and tar-gravel-roof per $m^2$ | 2.60 | -2.40 | -7.40 | |
| **Differences in NPV of green roof and tar-gravel-roof per $m^2$ p.a.** | **0.07** | **-0.06** | **-0.18** | |

## 6.5 Jena - Development of the new neighbourhood in Zwätzen

Oliver Gebhardt, UFZ

In the north of Jena, in the district of Zwätzen, a new neighbourhood will be developed. 350-400 housing units will inhabitant about 850-1.000 residents on a plot of 6.6 ha. The Department of City Planning is in charge of developing the public area in this new neighbourhood. Major stakeholders taking part in the planning process are potential residents and real estate developer. The City Council of Jena will have to approve the final draft of the land development plan for the area. Drafts have been developed by a planning and an architecture office in close cooperation with the Department of City Planning and repeatedly have been discussed internally and presented in participatory workshop in September 2014 to the public. Decision regarding the approval of the final draft of the land development plan is expected by the end of 2015.

**Figure 6.5-1: Edge-of-town location of the new neighbourhood Am Ölste**
Note: Are marked red.
Source: Landsat Image, Google Earth Pro

**Figure 6.5-2: Preliminary drafts of the new neighbourhood in Zwätzen presented in early 2014**

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

Jena is surrounded by steep shell limestone slopes, which operate as a thermal storage system making it one of the warmest places in Central Germany. Based on current climate projections an increase of heat stress events can be expected. Until the end of the century the average maximum temperature in summer will increase by 3 K (CMIP5, RCP 4.5) respectively 6 K (CMIP5, RCP 8.5) and the number of hot days will be up to three times (CMIP5, RCP 4.5) respectively four times (CMIP5, RCP 8.5) higher than under current climatic conditions. For the development of key parameters on the basis of different models and scenarios see Table 6.5-1. Despite the fact that the heat stress potential is lower in the suburban areas and the large housing estates located more distant to the city centre, e.g. the district Zwätzen, a substantial increase of the number and intensity of heat stress events has been projected also for those areas.

**Table 6.5-1: Selected climatic parameters (1981-2010, 2021-2050, 2071-2100)[46]**

| | 1981-2010 | 2021-2050 WETTREG A1B | 2021-2050 STAR A1B | 2021-2050 CMIP5 RCP4.5 | 2021-2050 CMIP5 RCP8.5 | 2071-2100 WETTREG A1B | 2071-2100 CMIP5 RCP4.5 | 2071-2100 CMIP5 RCP8.5 |
|---|---|---|---|---|---|---|---|---|
| $T_{max}$ in summer quarter (°C) | 24 | 26 | 25 | 25.7 | 26.4 | 28 | 27.2 | 30.2 |
| Number of hot days ($T_{max} \geq$ 30°C) | 11 | 19 | 20 | 18 | 22 | 39 | 35 | 49 |
| Precipitation in summer quarter (mm) | 160 | 185 | 170 | * | * | 175 | * | 135 |
| Number of sultry days (vapour pressure > 18,8 hPa) | 2.4 | 8.8 | 4.5 | - | - | 17.8 | - | - |

Note: *Standard deviation of natural variability of the parameter is higher than the signal determined by the model ensemble.

46 STAR (STAtistically based Regional climate model) and WettReg (WEaTher-Type based REGionalisation) are regional climate models which belong to the empirical statistical downscaling methods. Both models use global climate data from ECHAM5.

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

Various drafts have been discussed internally and with external partners in the 2014. On the basis of the feedback from all relevant stakeholders received at and as a follow-up to a participatory workshop Draft 2 (Figure 6.5-3) has been selected. A MCA is carried out comparing systematically potential variations of this draft to consider future climate change in today's decision-making processes. The aim is to support the design of a draft which on one hand suits current and future climatic conditions best but on the other hand also take into account additional factors affecting decision making, e.g. financial and aesthetic aspects.

**Figure 6.5-3: Two drafts of the new neighbourhood in Zwätzen presented at a participatory workshop in September 2014**

The variations of the current draft, which will be compared, are described in Table 6.5-2.

**Table 6.5-2: Description of adaptation measures for the new neighbourhood in Zwätzen**

| | **Alternative 1** | **Alternative 2** | **Alternative 3** |
|---|---|---|---|
| Number of trees | 152 | 246 | 241 |
| Type of newly planted trees | 25 large-crowned trees<br>127 small-crowned trees | 63 large-crowned trees<br>183 small-crowned trees | 142 large-crowned trees<br>99 small-crowned trees |
| Colour schemes of pavements | Sidewalks, Recreational area: ordinary pavements | Sidewalks: light-coloured pavements<br>Recreational area: ordinary pavements | Sidewalks, Recreational area: light-coloured pavements |
| Fountain | none | $50m^2$ | $100m^2$ |

Figure 6.5-4 presents a visualisation of Alternative 2 in the period 2071-2100.

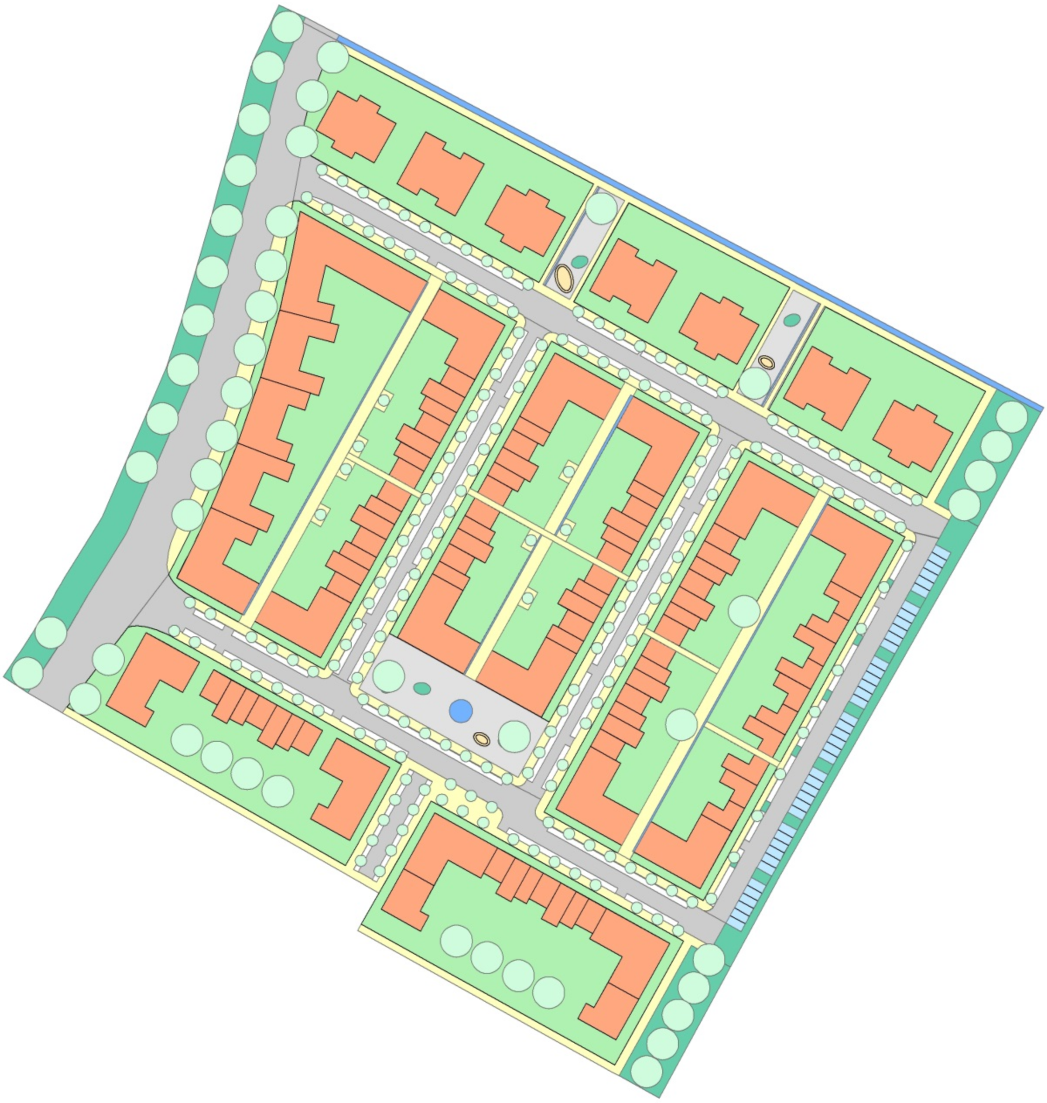


**Figure 6.5-4: Alternative 2, period 2071-2100**

**Step 3 - Evaluation Criteria and Method**

**Step 3a Selection of evaluation criteria**

The following criteria are chosen to compare the alternatives:

**Net present costs** (monetary) consist of the investment costs and the maintenance costs of the pavements and green structures, i.e. lawn and trees, and the investment costs of the fountain for the period 2018-2050 respectively 2018-2100. As recommended by national guideline a discount rate of 1.5% p.a. is applied.

The **heat stress potential** (quantitative) represents the heat stress level related to the respective alternative. It is determined with the URBAHT tool. For the long-term perspective average scores of the three periods indicated are used. For the mid-term perspective average scores of the first two time periods are used. The **architectural quality** of the drafts (qualitative) and the **amenity value** (qualitative) for residents and guests are also considered for the assessment. Furthermore, the marketing potential is included in the assessment.

**Step 3b Selection of evaluation method(s)**

Several assessment methods accounting differently for various types of uncertainty can be applied to determine the most appropriate alternative. Empirical evidence shows that multi-criteria analysis (MCA) is a promising tool to support such decision processes in the field of climate change adaptation. Multi-attribute decision making (MADM), a type of MCA, which compares pre-defined sets of alternatives are often used for applicability reasons. There are MADM concepts, which are based on multi attribute utility theory (MAUT) and so called outranking concepts, e.g. PROMETHEE, which perform pairwise comparisons of the criteria scores of all alternatives.

In contrast to MAUT approaches outranking concepts do not assume that decision-makers are completely aware of their preference structure. Furthermore, they can deal with uncertain, incomplete, differently scaled and inconsistent data. Applied in the traditional way, e.g. PROMETHEE I, they do not allow for compensation of positive and negative criteria scores. Thereby it is possible to discover unsolvable trade-off between alternatives. As PROMETHEE I provides partial pre-orders of alternatives, in these cases rankings will be incomplete. The advantage of identifying non-comparable measures is that the exchange amongst the different stakeholder-groups about the evaluation criteria and their weighting might be promoted. A complete ranking can be obtained if the so-called positive and negative preference flows are aggregated into net preference flows, which can easily be ordered (PROMETHEE II). If there are uncertainties in the criterion values which shall be considered in terms of score ranges, triangular distributions or any other probability functions Stochastic PROMETHEE II can be applied.

For this project multiple, differently scaled evaluation criteria are used to comparatively assess the alternative drafts. As for the determination of the UHI potential the RCPs 4.5 and 8.5 are used there is uncertainty concerning the performance of the alternatives with regard to this criterion. Therefore, **Stochastic PROMETHEE II** is applied for the assessment.

**Step 3c Weighting of evaluation criteria**

The planner being in charge of the project elicited the weights, as he was most familiar with all the feedback received in the course of the planning process and responsible for considering these claims and wishes when re-drafting the plan.

**Table 6.5-3: Criteria weighting new neighbourhood in Zwätzen**

| Criteria | Weights in % |
|---|---|
| Heat stress potential | 10 |
| Costs | 20 |
| Amenity value | 20 |
| Architectural quality | 30 |
| Marketing potential | 20 |

**Step 4 - Data collection**

The data used for the MCA comes from different sources. **Investment cost** data is provided by the Department of City Planning, private engineering offices, construction material companies and come from literature. **Maintenance costs** of the tree population are supplied by the municipal service company "KSJ" which is responsible for taking care of the green structures on public premises in Jena. The locational **heat stress potential** (UHI potential) unfolding, if drafts are implemented, is estimated using the modelling software Urban Heat Tool – URBAHT. The data on the structural parameters is determined on the basis of existing plans. The climatic data for applying URBAHT comes from two sources. The German National Meteorological Service (DWD) provided measurement data. Climate projection data was sourced from the KNMI Climate Explorer. Information on the alternatives' performances concerning the criteria **architectural quality**, **amenity value** and **marketing potential** is collected through expert judgments from the local planner. Table 6.5-4 and Table 6.5-5 give an overview of the data used.

**Table 6.5-4: Heat stress potentials of alternatives at the new neighbourhood in Zwätzen for the periods 1981-2010, 2021-2050, 2071-2100**

| Period | Alternative 1 | | | Alternative 2 | | | Alternative 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| **1981-2010** | | 2.6 | | | 2.4 | | | 2.3 | |
| **2021-2050** | | | | | | | | | |
| CMIP5 (RCP 4.5) | | 3.4 | | | 3.2 | | | 3.0 | |
| CMIP5 (RCP 8.5) | | 3.8 | | | 3.6 | | | 3.5 | |
| **2071-2100** | | | | | | | | | |
| CMIP5 (RCP 4.5) | | 4.2 | | | 3.9 | | | 3.7 | |
| CMIP5 (RCP 8.5) | | 6.1 | | | 5.7 | | | 5.5 | |
| **Minimum, mean, maximum value** | **Min** | **MV** | **Max** | **Min** | **MV** | **Max** | **Min** | **MV** | **Max** |
| Period 2021-2050 | 3.4 | 3.60 | 3.8 | 3.2 | 3.4 | 3.6 | 3.0 | 3.25 | 3.5 |
| Period 2071-2100 | 4.2 | 5.15 | 6.1 | 3.9 | 4.8 | 5.7 | 3.7 | 4.60 | 5.5 |

**Table 6.5-5: Data matrix new neighbourhood in Zwätzen**

| Criteria | Alternative 1 | | | Alternative 2 | | | Alternative 3 | | | IT[1] | PT[2] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min | MV | Max | Min | MV | Max | Min | MV | Max | | |
| **Heat stress potential** (2018-2050) | 4.20 | 4.30 | 4.40 | 3.90 | 4.00 | 4.10 | 3.85 | 3.95 | 4.05 | 0 | 3 |
| **Heat stress potential** (2018-2100) | 4.60 | 4.97 | 5.33 | 4.30 | 4.67 | 5.03 | 4.20 | 4.57 | 4.93 | 0 | 3 |
| **Net present costs** (2021-2050) | 9,232,599 | | | 9,505,652 | | | 9,552,137 | | | 10,000 | 400,000 |
| **Net present costs** (2021-2100) | 9,451,709 | | | 9,778,607 | | | 9,792,079 | | | 10,000 | 400,000 |
| **Amenity value** (2018-2100) (5-point Likert scale)[4] | 3 | | | 2 | | | 1 | | | 0 | 3 |
| **Architectural quality** (2018-2100) (5-point Likert scale)[3] | 3 | | | 2 | | | 2 | | | 0 | 3 |
| **Marketing potential** (2021-2100) (5-point Likert scale)[3] | 3 | | | 4 | | | 4 | | | 0 | 3 |

Notes: [1,2] The Indifference threshold [IT] and preference threshold [PT] are elements of the outranking concept and in particular the PROMETHEE method that forms the mathematical basis of PRIMATE. They are defined as follows: if the difference between the performances of two alternatives in the respective criterion is less than the indifference threshold the two alternatives are counted as indifferent, such that none is preferred to the other. If the difference is above the preference threshold the alternative with the better performance is strictly preferred to the other (mathematically it received a score of 1). If the difference is in between, the better alternative is weakly preferred to the other and received a score between 0 and 1, such that the score linearly increases with the difference between the performances (…) (Drechsler 2004: p. 3). [3,4] 1 – very good, 2 – good, 3 – average, 4 – poor, 5 – very poor.

**Step 5 – Evaluation and Prioritisation**

The MCA compares the alternatives described above. This implies that the status quo is due to the main goal of the planning process, i.e. the redevelopment of the area, not considered for the assessment. The application of the MCA approach Stochastic PROMETHEE II is facilitated by using software for Probabilistic Multi-Attribute Evaluation – PRIMATE (Drechsler 2004), which has already been tested in several pilot projects dealing with various aspects of climate change adaptation at the regional and local level. Therefore, the input data is processed with PRIMATE.

One option for considering uncertainty in criteria values in PRIMATE is through the use of score ranges, triangular or other probability distributions and the application of a Monte Carlo simulation approach. The resulting uncertainty of the final outcomes is documented in PRIMATE (see Figure 6.5-5 and Figure 6.5-6). The input data regarding the development of the heat stress potential is uncertain (see ranges in Table 6.5-5). For the assessment with PRIMATE a triangular distribution is used.

PRIMATE performs 10,000 runs and calculates for each alternative the outflow, i.e. the positive preference flow and extent to which the alternative outranks all other alternatives, the inflow, i.e. the negative preference flow and extent to which the alternative is outranked by all other alternatives and the net flows, i.e. the aggregation of positive and negative preference flows into a net preference flow. On the basis of these net flows a complete order of the alternatives can be established.

Figure 6.5-5 depicts the net flows of all alternatives for the period 2021-2050. The red bars represent the mean values of the net flows determined by 10,000 PRIMATE runs. The higher the net flow the better performs the respective alternative with regard to all evaluation criteria applied. The yellow uncertainty bar represents two standard deviations of the mean value of the net flows, i.e. about 95.4% of the net flows determined fall within this margin.

In the medium term as well as in the long-term Alternative 3 outperforms the other options (see Figure 6.5-5 and Figure 6.5-6). The level of uncertainty increases in time as the variation of important climatic parameters for RCP 4.5 and RCP 8.5 is more pronounced in the long run.

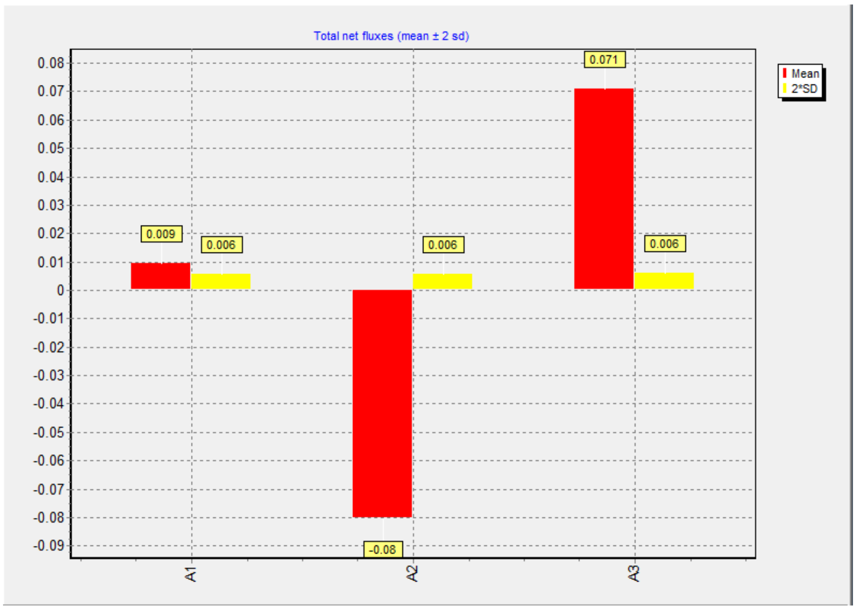



**Figure 6.5-5: Overall net flows of the alternatives for the period 2021-2050**

Note: The uncertainty bar represents two standard deviations of the mean value of the net flows, which means that about 95.4% of the net flows determined by 10,000 PRIMATE runs fall within this margin.

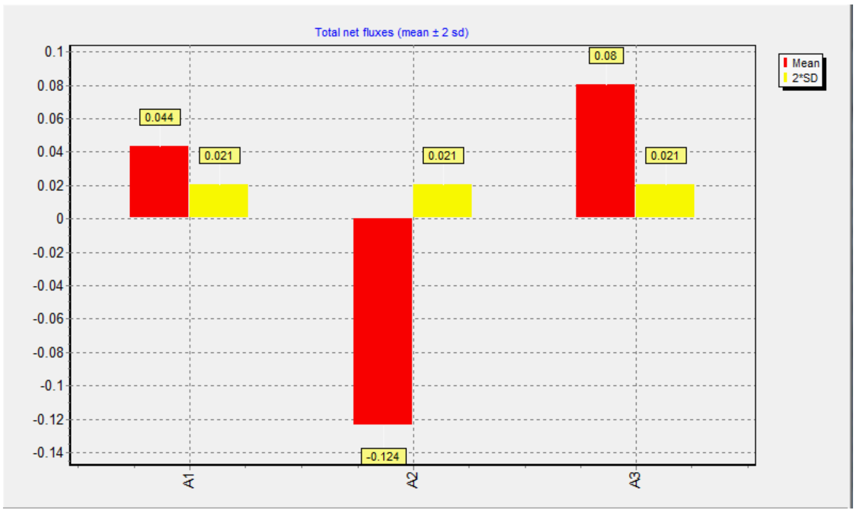



**Figure 6.5-6: Overall net flows of the alternatives for the period 2071-2100**

Note: The uncertainty bar represents two standard deviations of the mean value of the net flows, which means that about 95.4% of the net flows determined by 10,000 PRIMATE runs fall within this margin.

The heat stress potential scores for the three alternatives vary quite substantially as indicated by the net flows of the criterion heat stress potential (HSP) in Figure 6.5-7 and Figure 6.5-8. Alternative 3 also performs best in this regard.

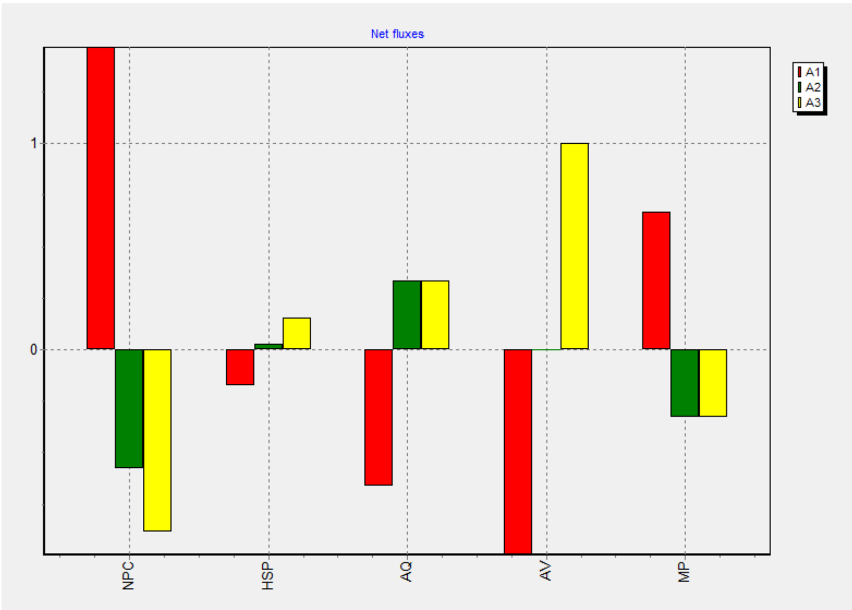



**Figure 6.5-7: Net flows by criterion for 2021-2050**

Notes: Alternative 1 – red bar, Alternative 2 – green bar, Alternative 3 – yellow bar; NPC – net present costs, HSP – heat stress potential, AQ – architectural quality, AV – amenity value.

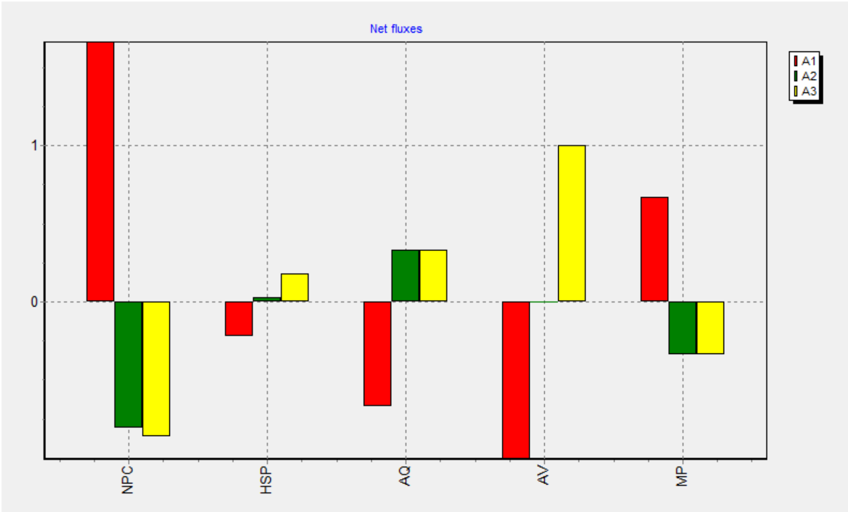



**Figure 6.5-8: Net flows by criterion for 2071-2100**

Notes: Alternative 1 – red bar, Alternative 2 – green bar, Alternative 3 – yellow bar; NPC – net present costs, HSP – heat stress potential, AQ – architectural quality, AV – amenity value.

The final result of the assessment can be presented as mean values of the overall net flows (and the corresponding standard deviations) or as a ranking of the alternatives. In the latter case the uncertainty of the result is expressed as a probability of an alternative to rank first, second and so on. Figure 6.5-9 illustrates the ranking of the alternatives for the period 2021-2050 and Figure 6.5-10 for the period 2071-2100. Unsurprisingly, the rankings are in accordance with the order of the net flows (see Figure 6.5-5 and Figure 6.5-6). With a probability of 100% respectively 98% Alternative 3 ranks first.

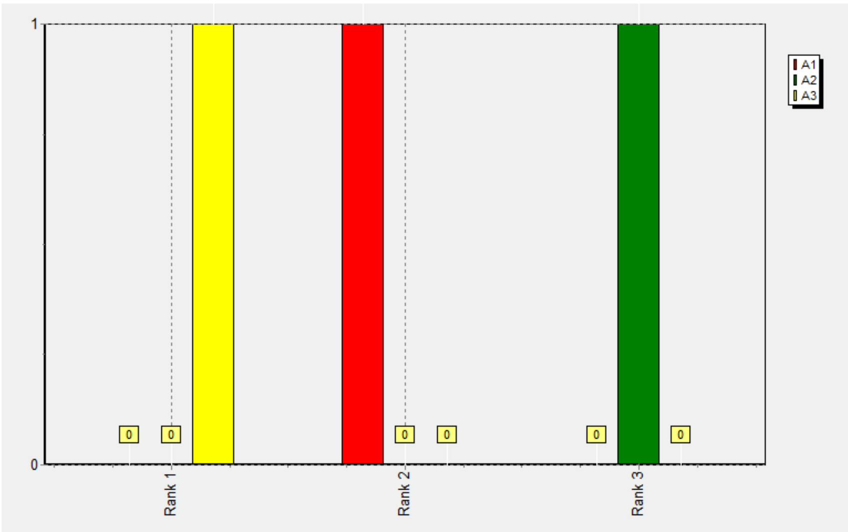



**Figure 6.5-9: Overall ranking of the alternatives for the period 2021-2050**

Notes: Alternative 1 – red bar, Alternative 2 – green bar, Alternative 3 – yellow bar

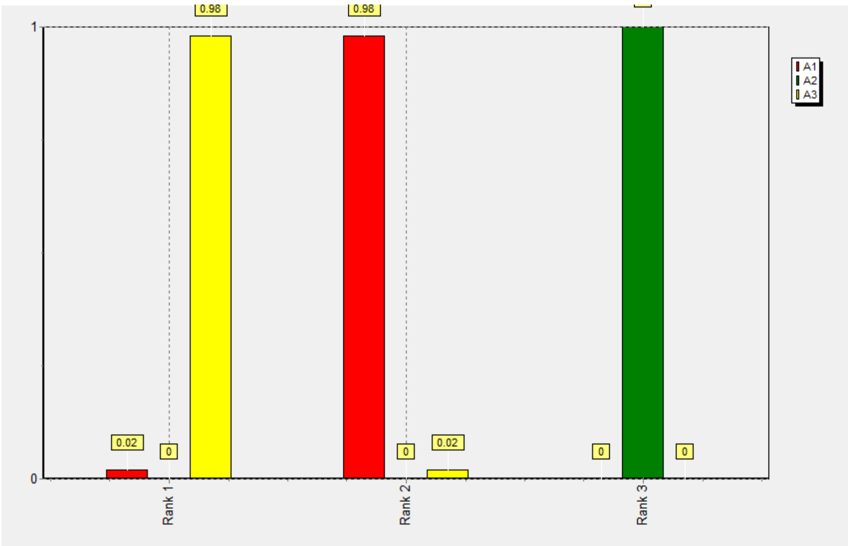



**Figure 6.5-10: Overall ranking of the alternatives for the period 2071-2100**
Notes: Alternative 1 – red bar, Alternative 2 – green bar, Alternative 3 – yellow bar

These are the main results of the multi-criteria assessment for the new neighbourhood in Zwätzen:

- Alternative 3 ranks first, alternative 1 second and alternative 2 third in the medium-term as well as in the long-term perspective.
- In the medium-term perspective this result is certain. In the long-term perspective the respective probabilities for this ranking are 98% of alternative 3 ranking first, 98% of alternative 3 ranking second and 100% of alternative 2 ranking third. Uncertainty in the results is a consequence of the uncertainty in climate input data and comparatively low. Results are statistically significant.
- Performance of alternatives varies substantially across the criteria. With regard to the criteria costs (20%) and marketing potential (20%) alternative 1 clearly outperforms alternative 3, which in turn performs much better regarding the criteria architectural quality (30%), amenity value (20%) and heat stress potential (10%). The at first sight seemingly small differences between alternative 2 and 3 turn out to have a major impact on the overall assessment result.
- The overall effect of the use of light-coloured paving materials as well as large-crowned trees on the heat stress potential and the amenity value is much more beneficial than additional financial burden caused by these adaptation measures.
- Although the greener alternatives perform well with regard to the criteria amenity value and architectural quality, they – against the prevailing assumption – do not always enhance the marketing potential of a property. This points to the negative aspects associated with green infrastructures, e.g. less incidence of light, higher energy costs in winter and other disturbance.

## What are the main lessons learnt from your case study?

The following information relates to all three assessments carried out in Jena.

**Transferable results?**

Light-coloured pavements and large-crowned trees have very beneficial impacts on site-specific microclimate. The slightly higher costs (light-coloured pavements) also pay-off with regard to rather aesthetic aspects. Overall costs (procurement, planting, replanting, care) of small-crowned trees are in a long-term perspective (> 40 years) slightly higher than for large-crowned trees. Artificial water courses have a limited impact on the site-specific microclimate and are quite costly. Their overall value rather dependents on the aesthetic preferences of the stakeholders.

For specific figures, please, see D5.2 Table 3-1.

**Lessons learnt with regard to the process of economic evaluation (in urban planning)?**

First preliminary results suggest that adaptation-related assessments at a later stage of the planning process are more likely to be considered, because at the early planning stages the balancing of many other aspects, which are considered to be more important than climate change adaptation, dominates the exchange between planners and stakeholders.

Potential conflicts of adaption and mitigation efforts can be solved or at least mitigated by explicitly addressing these issues at an early stage of strategy and project development.

The exchange between representatives of different administrative bodies and scientists should be institutionalized and take place on a regular basis. As up to now the low level of formal institutionalisation of adaptation makes it strongly dependent on the determination of interested individuals. Despite a multitude of information and tools climate change adaptation is (still) a subordinated matter in urban planning in Germany.

In-house trainings of planning departments are essential to improve the ability of the municipal staff to use data and tools available for supporting adaptation.

Adaptation-related outreach activities do not only raise awareness but also ensure the support of the general public.

The public commitment of political decision-makers to support local adaptation activities is pivotal.

The momentum created, e.g. by the initial adoption of an adaptation strategy, can be maintained through projects that continuously update and expand the existing knowledge base.

**Feasibility of methods?**

MCA is a useful decision support method for mainstreaming climate change adaptation into urban planning routines.

PRIMATE is capable of dealing with data uncertainties probabilistically and allows for simultaneous consideration of varying stakeholder preferences.

URBAHT results do not compare with those of sophisticated software packages for microclimatic modelling, but the tool’s comparatively low data requirements and immediate results enhance the probability of application and integration of heat stress-related considerations into established planning routines.

**Important data sources?**

Investment cost data was primarily sourced from the Department of City Planning, private planning consultancies, private engineering offices, construction material companies and literature. Maintenance costs were provided through the municipal service company. The German National Meteorological Service (DWD) provided measurement data. Climate projection data was sourced from the KNMI Climate Explorer. Information on the alternatives’ performances concerning the rather aesthetic criteria was collected through expert judgments.

## 6.6 Prague

Eliška Lorencová, Marie Hubatová, Blanka Loučková, David Vačkář, CzechGlobe

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

**What is the climate change related problem/risk you would like to reduce by adaptation?**

The Czech Republic is one of the European countries most threatened by future floods in terms of extent and cost of possible damage, and it is therefore absolutely crucial to invest in adaptation and flood protection measures (Rojas et al., 2013). In recent years, Prague has experienced an increased frequency and strength of these events (the greatest one in 2002) and regarding to future climate projections, this trend is very likely to continue.

Adaptation measures to minimise the vulnerability of the city to these events are absolutely crucial. The most threatened are especially buildings, infrastructure (including Prague metro), businesses, public health, environment and historical heritage.

Measures already in place (only measures within the area of the city are taken into consideration):

- Non-structural measures: disaster response management, risk transfer tools, monitoring and management
- Structural: Improving flood defences (engineering)

The risks change due to both, climate and socio-economic change. The changing climate can significantly increase the character of future events, especially in terms of frequency and flow rate. Socio-economic change may change the risk in terms of development/settlement or abandonment of potentially flooded and therefore threatened areas.

Drivers: precipitation

- Clusters: infrastructure, human health, water management

Scenarios: The case study is rather static and is based on the city local plan and therefore does not use any climate or socio-economic scenarios.

**Which adaptation tipping points can be identified?**

The tipping points are very difficult to be defined for this case study and our approach as the measures are already in place and these should withstand even a very extreme event such as a 500-year flood.

The point where protection standards can no longer be met financially (as flood risk and required investments in protection are becoming too high) is quite unlikely to be reached in any closer future, especially within current urban plan of the city. If there were any extreme changes (for example massive settlement in unprotected areas in flooded zones), the critical levels might be reached more easily and sooner, however this situation is very improbable.

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

**What are the alternative adaptation measures?**

The primary objective of the adaptation is to protect the city from floods and to prevent damages, which could be potentially caused by such events. The objective is not only physical protection but also to create such an integrated risk management approach, which would enable to deal with these events in the most efficient and controllable way.

Potential measures are of two kinds, structural (engineering solution = flood control system) and non-structural measures (awareness raising, disaster response management, risk transfer tools, monitoring and management).

For the baseline strategy it is assumed that the flood protection is maintained on the same level as it was in 2002 before the great flood event. The baseline includes no adaptation measures and no increasing threats caused by climate change are taken into account. The baseline includes neither backlog of investment realised before 2002 nor autonomous/non-planned adaptation.

Measures are fully compatible and interdependent, so they need to be bundled in order to be efficient and work properly.

**What are alternative adaptation pathways?**

The measures should handle the flow rate of 500-year floods and it is therefore not very likely that they will fail to meet the objectives in any closer future (in case the management measures work properly).

In general, there are no such measures, which would be competitive with the current system, mainly due to the extent of floods Prague has to face. The current system could be for sure enhanced and/or complemented by some ecosystem-based measures. These would, however, not be able to provide such a protection as the conventional measures and would only serve as a supplement to the original system.

**Developing adaptation pathways: Urban heat island in Prague**

The number and intensity of hot days have considerably increased in the last three decades and it is nearly certain that there will be more frequent hot extremes in the second half of the 21st century.

The impact of heat waves is particularly strong in cities and towns due to the UHI effect. In Europe, in the last decades, heat waves have caused the most human fatalities of the natural disasters (EEA 2012). In 2003 the European heat wave resulted in 40,000 excess deaths (García-Herrera et al. 2010)

Moreover, in the future, urban areas are expected to suffer more due to the combined outcome of climate change and the urban heat island (UHI) effect (IPCC 2014). UHI effect shows the increased urban air temperature compared to surrounding rural areas, where the temperature difference can be up to 10 °C or more (EEA 2012). The most common effect of UHI is accumulation of heat in urbanized areas, which results in higher temperatures, especially at night, compare to the surrounding non-built up areas (IPCC 2013). UHI effect rises the number of hot days (and nights), duration of heat waves, affects health impacts and, subsequent mortality (Salcedo Rahola et al. 2009).

In order to respond to the UHI effect in the urban area, it is necessary to implement suitable adaptation measures. The table below provides comprehensive overview of particular adaptation measures related to heat stress.

**Table 6.6-1: Overview of particular adaptation measures to heat stress**

| Adaptation measures to heat stress | | |
|---|---|---|
| **Green measures** | **Soft measures** | **Grey measures** |
| Support of green infrastructure<br>• Green areas<br>• Street vegetation<br>• Green roofs<br>• Green facades<br>• Ensure sustainable watering | • Support to vulnerable groups (identification, distribution, targeted action)<br>• Information on adapting behaviour during heat waves particularly to vulnerable<br>• Preparedness of medical care | • Urban design to provide shade (orientation/reduce sun exposure/wind direction, compact buildings) |
| Support of blue infrastructure<br>• Open water, fountains<br>• Small ponds | • Considering UHI reduction in urban planning | • Building insulation |
| • Ensuring wind flow<br>• Fresh air form greenery outside the city can flow in | • Heat waves warning systems<br>• Heat action plans including appropriate institutional structures<br>• Monitoring and inspection | • Cooling (air conditioning)<br>• Passive cooling of the buildings<br>• Blinds, shutters to provide shade |
| • Wetting streets and roofs | • Awareness raising, ensuring broad participation | • Increase albedo (reflecting levels) of roofs, pavements |
| | • Adapting building codes to include insulation and shadowing against heat waves | |
| | • Mapping of UHI and cool places | |

Sources: Based on EEA (2012), Runhaar et al (2012)

**Case of Prague UHI**

In the case of Prague, urban heat island has already occurred and is becoming more serious. According to the outcomes of UHI project (http://eu-uhi.eu/), its annual average intensity during the period 1961-2012 was 2.2°C with a peak during June and July (2.4°C). The intensity of the heat island has been increasing in last years, especially during summer months, almost by 0.5°C.

**Research objective**

Taking into account impact of climate change, potential adaptation measures and spatial planning, we aim to explore adaptation pathways of Prague UHI, within the time frame 2014-2100.

**Methods**

*Study area:* For modelling purposes, we selected particular area in Prague 6 - Dejvice (see Figure 6.6-1 and Figure 6.6-2).


**Figure 6.6-1: Selected case study area in Prague**
Source: Google maps

**Figure 6.6-2: Selected case study area – ortophoto**
Source: Zabaged

**Table 6.6-2: Classification of current land use**

| Land use categories | Area covered (%) |
|---|---|
| Impervious area without buildings | 14,5 |
| Impervious area with buildings | 39,3 |
| Water area | 0 |
| Lawn/meadow area | 6,5 |
| Shrub area | 0 |
| Tree area | 5,6 |
| Buildings mixed type I* | 28,3 |
| Buildings mixed type II** | 5,8 |

Note: * Apart from buildings include 10% tree area, 10% meadow)

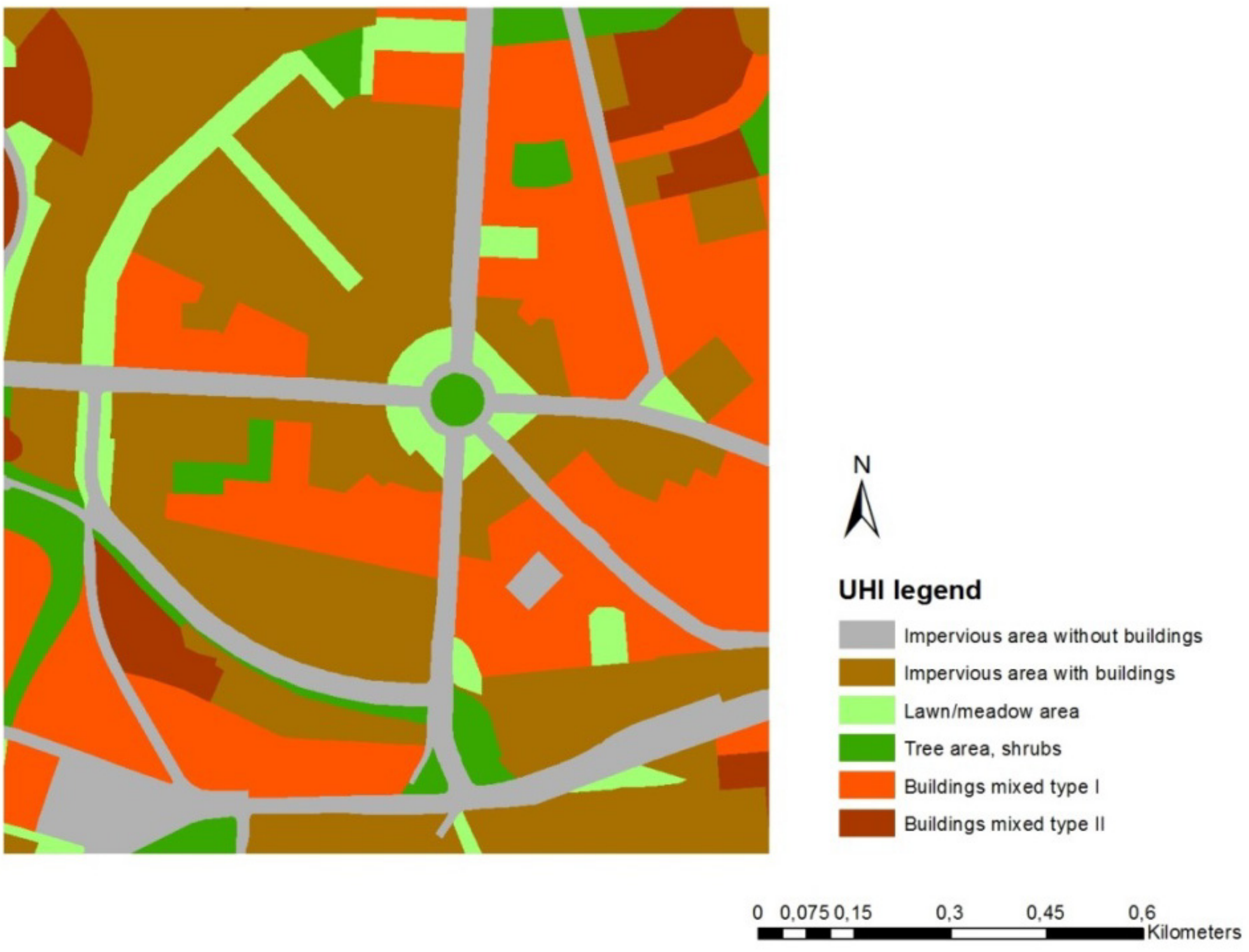



**Figure 6.6-3: Land use classification**
Source: Based on Spatial plan of Prague.

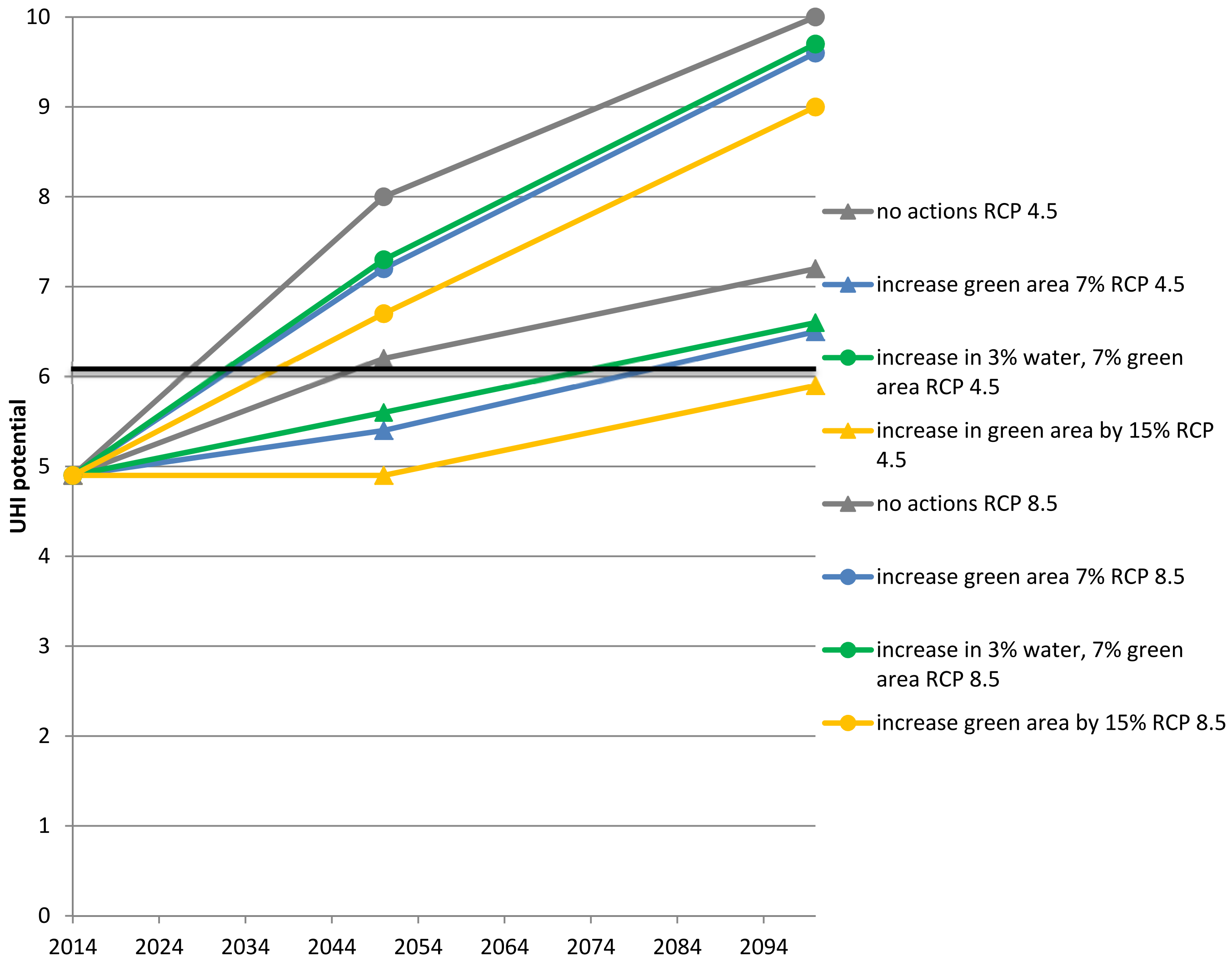



**Figure 6.6-4: Calculation of adaptation tipping points**

Adaptation pathways approach was applied to assess future climate change impacts and potential adaptation measures. Firstly, we calculated tipping points for particular actions and scenarios - RCP 4.5, RCP 8.5 (see Figure 6.6-4).

Adaptation pathways were developed for the three selected adaptation measures (see Figure 6.6-5):

1. Increase in green area by 15%,
2. Water area increased by 3%, green area by 7%
3. Increase in green area by 7%,

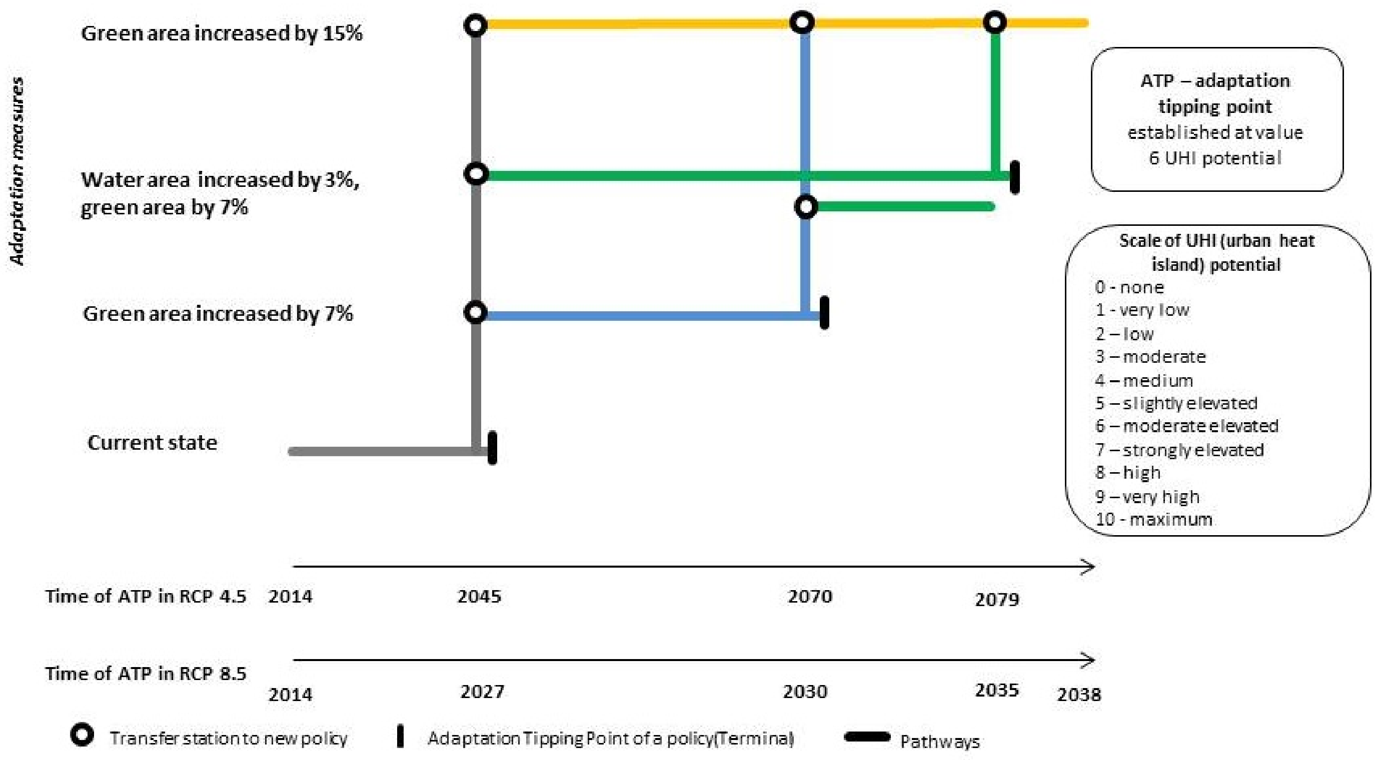



**Figure 6.6-5: Adaptation pathways – UHI in Prague**

Some of the findings:

- Moderate elevated value (6) of UHI potential selected as adaptation tipping point
- In case of RCP 4.5, adaptation measures have substantial impact on UHI reduction
- UHI potential is significantly increasing in RCP 8.5, adaptation measures sufficient only to year 2033. Therefore, need for other adaption options.

**Step 3 - Evaluation Criteria and Method**

**Step 3a Selection of evaluation criteria**

**Which evaluation criteria should be used?**

Costs: cost of planning and realisation of the measures (specifically the costs of flood control system), costs of installation (in case of an event occurrence), costs of maintenance and storage. Also, some minor damages may occur even despite the FCS, especially during greater events. These need to be considered as well.

Benefits: avoided costs on damaged/destroyed buildings, infrastructure, and industries, avoided costs of damaged equipment and machinery, avoided costs of evacuation, avoided costs of cleaning, avoided costs on damaged environment and cultural damage.

All the costs and benefits mentioned will be measured and compared in monetary terms.

**Step 3b Selection of evaluation method(s)**

**What is the appropriate evaluation method?**

Cost-benefit analysis

**Step 4 - Data collection**

**What are the costs and what are the benefits of the alternative adaptation options?**

The main data used for this case study are information about costs of the adaptation measures, flood maps, historical data about the costs caused by the floods in 2002. The data were not publicly available which caused a slight delay. We have, however, already received all the data we needed for the case study. The costs and benefits are described in the table below. Particular calculations can be found in the Annex.

If we compare the costs and benefits for each flow rate, we can see that the benefits are greater than costs for the flow rate of Q50 and more. Even if we considered such a scenario where there would be just one event of Q50 (or more) during the expected life span of the measures (about 80 years), the benefits would still overweight the costs even despite the annual maintenance and storage costs. Based on our calculations we can say that if there occur at least one event of Q50/100/500, or Q20 with a combination with another event (Q20/50/100/500), or any combination of these, the FCS investment will return.

It is also important to mention that this analysis does not consider any possible impacts of floods on mental health and comfort of people affected by the event. These aspects are very hard to describe and measure and even harder to put a value on.

**Table 6.6-3: Overview cost and benefit data**

**What is the evaluation time frame?**

| | Item | Source | Q20 | Q50 | Q100 | Q500 | Units |
|---|---|---|---|---|---|---|---|
| **costs** | Total cost of FCS | Prague council | 144.4 | 144.4 | 144.4 | 144.4 | M EUR (2013) |
| | Installation[47] (per event) | Prague council | 0.65 | 0.65 | 0.65 | 0.65 | M EUR (2013) |
| | Maintenance, storage (annual) | Prague council | 0.89 | 0.89 | 0.89 | 0.89 | M EUR (2013) |
| | **TOTAL COSTS** | | **145.94** | **145.94** | **145.94** | **145.94** | **M EUR (2013)** |
| **benefits** | Avoided costs of residential buildings | Own calculation based on data by Institute of planning and development in Prague, Czech association of estate agencies[48] | 332.27 | 697.6 | 1349.22 | 1971.31 | M EUR (2013) |
| | Avoided costs of infrastructure | Prague council, own calculations | 40.28 | 66.07 | 106.6 | 143.07 | M EUR (2013) |
| | Avoided costs of industrial buildings | Prague council, own calculations | 84.71 | 222.5 | 344.47 | 470.69 | M EUR (2013) |
| | Avoided costs of equipment | Prague council, own calculations | 42.19 | 102.14 | 171.14 | 254.16 | M EUR (2013) |
| | Avoided costs of evacuation | Prague council, own calculations | 0.04 | 0.07 | 0.15 | 0.25 | M EUR (2013) |
| | Avoided costs of cleaning and other costs[49] | Prague council, own calculations | 42.36 | 51.69 | 62.66 | 73.49 | M EUR (2013) |
| | Avoided costs of cultural damage | Prague council, own calculations | 21.84 | 30.5 | 37.82 | 42.93 | M EUR (2013) |
| | Avoided costs of environmental damage | Prague council, own calculations | 16.55 | 18.03 | 19.62 | 13.66 | M EUR (2013) |
| | Costs caused despite FCS | Own calculations (for details see Annexes) | -409.57 | -525.89 | -627.58 | -966.12 | M EUR (2013) |
| | **TOTAL BENEFITS** | | **170.67** | **662.71** | **1464.1** | **2003.44** | **M EUR (2013)** |

[47] Most of the costs are fixed no matter what the final flow rate is.
[48] http://cenovamapa.gekonsro.cz/
[49] Other costs include costs of demolitions, refill of the grit underlying inrastructure

We assume that the lifespan 80 years and therefore we calculated the future prospect till 2095.

**Which discount rate should be applied?**

There is no national guideline for climate change adaptation measures in the Czech Republic. The discount rate applied would be 3% with a sensitivity test of 1 and 5%.

**How to deal with data uncertainty?**

Data uncertainty is quite high and therefore average or "as close as possible" data will be used for the analysis. Such items where the uncertainty is too high (e.g. impact on businesses) will not be included in the analysis.

**Step 5 – Evaluation and Prioritization**

**What is the ranking order of alternative adaptation options (measures, bundles of measures or pathways)?**

Even without the future climate scenarios it is quite obvious that the benefits of the FCS are greater than the costs. The overall comparison however depends on the frequency and strength of forthcoming events, especially due to some fixed costs, which occur annually and independently on any climate development. We considered an event to occur approximately every twenty years.

**For cost-benefit analysis**

**What is the net-present value (discounted benefits – discounted costs)?**

The ADD equals to 37 m EUR. The results are following:

- For 3% discount rate: NPV=918 m EUR.
- For 1% discount rate: NPV=1,872 m EUR.
- For 5% discount rate: NPV=599 m EUR.

**What are the uncertainties associated with the performance of the different options?**

In this analysis we focused on the flood protection of the most endangered parts of Prague. The whole FCS is quite massive and absolutely adequate to the potential risk and vulnerability. In general there are no different options to ensure flood protection of Prague at such a level. Probably some minor adjustments or changes are possible, including implementation of more green measures or other management systems. These would, however, only have small effects and within the context of to the current FCS costs would be rather negligible.

**Is there and, if so, to what extent uncertainty in the ranking of options?**

Not relevant

**Is it possible to determine which option most likely performs best or is it necessary to gather further information to reduce uncertainty?**

Not relevant

## What are the main lessons learnt from your case study?

**Transferable results?**

In general, the results are not very transferable due to the unique case of every city (e.g. structure, geographic position and climate conditions). We could, however, assume that such an adaptation system (not particular measures but rather the overall approach) may be suitable for a city, which could be affected in a similar way as Prague.

**Lessons learnt with regard to the process of economic evaluation?**

The main lesson is probably the fact that it all depends on the input data and their quality. In our case it would not be feasible to undergo an in-depth evaluation because the extent of the study would be enormous and way beyond the scale of this project. On the other hand, we believe that for our purposes the method was perfectly appropriate.

**Feasibility of methods?**

The methods were feasible but only in the extent mentioned above. The results are rather approximate than precise. This is caused not only by the high limitations of our data (most of the values were rounded and even the flood maps provided by the Institute of planning and development in Prague are only based on mathematical models and are probably not very precise). Besides that, it is very important to keep in mind that the whole FCS is managed by people and is strongly dependent on their judgement, access to information and flexibility.

Another point is the suitability of this method for this evaluation in general. It would be probably better to apply some combined method, which would enable an interpretation of non-monetary values or socio-economic and cultural consequences as well. For example due to the FCS in Prague, there are greater damages caused to the environment, mainly because the flood barriers prevent the river to burst its banks in residential areas and rather pushes it to green spots around the city. Measures similar to this one are very difficult to measure in monetary terms because any further consequences and wider context are omitted.

**Important data sources?**

Two most important data sources for the flood case study were especially Prague council and the Institute of planning and development in Prague. Both these institutions were great sources of data and information.

**Annex**

**Calculations of the costs**

**Total costs**

Prague council provided the data about total costs of Prague FCS. The flood control system was built in seven stages and was finished in 2013. The overview of the whole system including costs is described in the table below. The total value was calculated in 2012, before finishing the last stage of the FCS. These costs are fixed and the same for any flow rate.

**Table 6.6-4: Structure of flood control system (FCS)**

| FSC in 2014 | Extent | Units |
|---|---|---|
| Fixed measures | 12,460 | Meters |
| Mobile measures | 6,795 | Meters |
| Heavy mobile measures | 130 | Meters |
| Measures- sum | 19,255 | Meters |
| Total costs | 3,700,000,000 | CZK |

The value in the 2013 prices would be (using average annual inflation rate[50] 1.4%): 3 751.8 m CZK

The value in EUR would be (using average annual exchange rate for 2013[51] 25.987 CZK/EUR): 144.4 m EUR

**Installation**

According to Prague council, the costs of installation of all mobile and heavy mobile measures (including the sealing of the harbour in Prague-Liben, Certovka channel and Rokytka river - a tributary of the Vltava, and the activation of water pumps in the canalisation system) is 17 m CZK, which means 0.65 m EUR. These costs are fixed and the same for any flow rate.

**Maintenance and storage**

According to the Prague council, the costs of maintenance and storage equal 23 m CZK (0.89 m EUR). As stated by the council, these costs can rise even by a few millions CZK in case any technical problems or reparation costs occur. As these extra costs are unpredictable, we have decided not to take them into account and only consider the costs of storage and maintenance. These costs are fixed and the same for any flow rate.

**Costs caused despite the FCS**

For all the categories, we calculated costs of damage, which occur even despite the FCS. The results are shown in the following table in both, original CZK values (2013 levels) and EUR (converted by the average exchange rate in 2013).

In the case of residential building where we were able to calculate the costs directly using GIS.

For infrastructure, industries, cultural and environmental costs (the categories where there was not enough data to calculate their costs for different flow rates) we used the Q2002 costs as a referral point. For each category we calculated a share of area affected within different flow rates in GIS and then applied these shares for the costs from 2002 (at their 2013 levels). The main reasons to use this method were a lack of data and an assumption that the prices and location of these have not changed too much.

For equipment we calculated the proportion of all residential and industrial areas flooded compare to the flooded areas in Q2002. Then we compared these spatial proportions with the costs of damaged equipment from the referral point (Q2002 at 2013 price levels).

For the costs of evacuation we compared spatial proportions of flooded residential areas to the referral point (Q2002) and based on these shares we calculated the costs of evacuation (at 2013 price levels).

[50] Czech Statistical Office: http://www.czso.cz/csu/redakce.nsf/i/mira_inflace
[51] EUROSTAT: http://epp.eurostat.ec.europa.eu/portal/page/portal/exchange_rates/data/main_tables

For the “Other” category we compared spatial proportions of the total flooded area to the referral point (Q2002) and based on that we calculated the costs of this category (at 2013 price levels).

The detailed costs are described in Table 6.6-5.

Table 6.6-6 shows the total costs for each flow rate.

**Table 6.6-5: Detailed costs for flow rate Q20, Q50, Q100 and Q500**

| | | Residential | Infrastr. | Industries | Equipment | Evacuation | Other | Cultural | Envi. |
|---|---|---|---|---|---|---|---|---|---|
| **Q20** | CZK (mil) | 5,222.23 | 991.89 | 1,715.57 | 792.76 | 0.58 | 1,029.98 | 503.87 | 394.16 |
| | EUR (mil) | 200.96 | 38.17 | 66.02 | 30.51 | 0.02 | 39.63 | 19.39 | 15.17 |
| % of Q2002 | | *N/A* | 27 | 14 | 12 | 9 | 54 | 45 | 111 |
| **Q50** | CZK (mil) | 6,191.81 | 1,373.08 | 2,802.86 | 1,182.48 | 0.7 | 1,139.51 | 558.69 | 417.81 |
| | EUR (mil) | 238.23 | 52.84 | 107.86 | 45.5 | 0.03 | 43.85 | 21.5 | 16.08 |
| % of Q2002 | | *N/A* | 37 | 23 | 18 | 11 | 60 | 50 | 117 |
| **Q100** | CZK (mil) | 7,288.91 | 1,772.7 | 3,480.39 | 1,456.83 | 0.83 | 1,259.83 | 604.43 | 445.13 |
| | EUR (mil) | 280.48 | 68.21 | 133.93 | 56.06 | 0.03 | 48.48 | 23.26 | 17.13 |
| % of Q2002 | | *N/A* | 48 | 29 | 22 | 13 | 66 | 54 | 125 |
| **Q500** | CZK (mil) | 14,313.06 | 2,199.89 | 4,093.95 | 1,994.24 | 1.67 | 1,362.31 | 673.45 | 468.21 |
| | EUR (mil) | 550.78 | 84.65 | 157.54 | 76.74 | 0.06 | 52.42 | 25.91 | 18.02 |
| % of Q2002 | | *N/A* | 59 | 33 | 30 | 26 | 71 | 60 | 132 |

**Table 6.6-6: Total costs for flow rate Q20, Q50, Q100 and Q500**

| | Q20 | Q50 | Q100 | Q500 |
|---|---|---|---|---|
| CZK (m) | 10,650.17 | 13,666.94 | 16,309.05 | 25,106.78 |
| EUR (m) | 409.57 | 525.89 | 627.58 | 966.12 |

**Calculations of the benefits**

*Avoided costs of residential buildings*

The final rates were calculated in GIS in following steps:

Based on the data provided by the Institute of planning and development in Prague (flood maps for different flow rates with and without the FCS, terrain map and local plan) we calculated the depth of water in flooded parts of the city for particular flow rates and use/absence of FCS.

We collected information regarding market prices of residential buildings in the flood-prone areas from Czech association of estate agencies.

We used the methodology by Genovese (2006) to calculate the final damage on residential buildings. This method is based on a formula described below. The data on facilities and equipment of households are a part of separate category.

Buildings:

DAMAGE = p * A * H * V

p – percentage of urban fabric covered surface in the particular land use

A – area ($m^2$) of the land use

H – water depth damage factor

V – average price for $m^2$ for an apartment

The values were calculated in 2013 prices for particular flow rates with following results described in the table. The values were also converted to EUR using the average exchange rate for 2013.

**Table 6.6-7: Avoided costs of residential buildings**

| | Q20 | Q50 | Q100 | Q500 |
|---|---|---|---|---|
| CZK (m) | 8,634.75 | 18,128.42 | 35,062.21 | 51,228.46 |
| EUR (m) | 332.27 | 697.6 | 1,349.22 | 1,971.31 |

**Avoided costs of infrastructure**

The costs of damaged infrastructure were, according to Prague council, 2,893 m CZK during the event in 2002. This amount includes costs of damaged bridges, roads, rails, telecommunications, engineering sites and buildings, water bodies and other infrastructure units.

The costs were adjusted for the prices in 2013 based on the average annual inflation rate of 2.31%: 3,717.9 m CZK.

The costs were adjusted for particular flow rates. These numbers were calculated as ratios of the original amount and the proportion of area flooded by particular flow rate.

**Table 6.6-8: Avoided costs of infrastructure**

| | Q20 | Q50 | Q100 | Q500 |
|---|---|---|---|---|
| CZK (m) | 1,046.63 | 1,716.85 | 2,770.21 | 3,717.9 |
| EUR (m) | 40.28 | 66.07 | 106.6 | 143.07 |
| % of Q2002 | 28 | 46 | 75 | 100 |

**Avoided costs for industries**

The costs of industrial damage were, according to Prague council, 9,517.9 m CZK during the event in 2002. This amount includes costs of damaged industrial buildings and factories. The costs of damaged equipment are a part of the equipment category.

The costs were adjusted for the prices in 2013 based on the average annual inflation rate of 2.31%: 12,231.8 m CZK.

The costs were adjusted for particular flow rates. These numbers were calculated as ratios of the original amount and the proportion of area flooded by particular flow rate.

**Table 6.6-9: Avoided costs for industries**

| | Q20 | Q50 | Q100 | Q500 |
|---|---|---|---|---|
| CZK (m) | 2,201.39 | 5,782.22 | 8,951.78 | 12,231.8 |
| EUR (m) | 84.71 | 222.5 | 344.47 | 470.69 |
| % of Q2002 | 18 | 47 | 73 | 100 |

**Avoided costs of equipment**

The costs of damaged infrastructure were, according to Prague council, 5,137 m CZK during the event in 2002. This amount includes costs of damaged machinery, vehicles and equipment, manufacturing stocks, commercial stocks, and indoor households equipment.

The costs were adjusted for the prices in 2013 based on the average annual inflation rate of 2.31%: 6,604.8 m CZK.

The costs were adjusted for particular flow rates. These numbers were calculated as ratios of the original amount and the proportion of area flooded by particular flow rate.

**Table 6.6-10: Avoided costs of equipment**

| | Q20 | Q50 | Q100 | Q500 |
|---|---|---|---|---|
| CZK (m) | 1,096.51 | 2,654.28 | 4,447.3 | 6,604.8 |
| EUR (m) | 42.19 | 102.14 | 171.14 | 254.16 |
| % of Q2002 | 17 | 40 | 67 | 100 |

**Avoided costs of evacuation**

The costs of evacuation were, according to Prague council, around 5 m CZK during the event in 2002. Even though there were around 50,000 people who lived in the flooded areas at that time, only 10% of them used the evacuation services and shelters provided by the city districts involved. A majority of the inhabitants affected stayed at their relatives or at their summerhouses.

The costs were adjusted for the prices in 2013 based on the average annual inflation rate of 2.31%: 6.4 m CZK

The costs were adjusted for particular flow rates. These numbers were calculated as ratios of the original amount and the proportion of area flooded by particular flow rate. For the costs of evacuation we compared spatial proportions of flooded residential areas to the referral point (Q2002) and based on these shares we calculated the costs of evacuation (at 2013 price levels).

**Table 6.6-11: Avoided costs of evacuation**

| | Q20 | Q50 | Q100 | Q500 |
|---|---|---|---|---|
| CZK (m) | 0.96 | 1.92 | 3.84 | 6.4 |
| EUR (m) | 0.04 | 0.07 | 0.15 | 0.25 |
| % of Q2002 | 15 | 30 | 60 | 100 |

**Avoided costs of cleaning and other expenses**

The costs of damaged infrastructure were, according to Prague council, 1,486 m CZK during the event in 2002. This amount includes costs of cleaning, demolitions, refill of the grit underlying infrastructure and other costs, which are not a part of any other category.

The costs were adjusted for the prices in 2013 based on the average annual inflation rate of 2.31%: 1,909.7 m CZK.

The costs were adjusted for particular flow rates. These numbers were calculated as ratios of the original amount and the proportion of area flooded by particular flow rate.

**Table 6.6-12: Avoided costs of cleaning and other expenses**

| | Q20 | Q50 | Q100 | Q500 |
|---|---|---|---|---|
| CZK (m) | 1,100.78 | 1,343.14 | 1,628.25 | 1,909.7 |
| EUR (m) | 42.36 | 51.69 | 62.66 | 73.49 |
| % of Q2002 | 58 | 70 | 85 | 100 |

**Avoided cultural costs**

The costs of damaged infrastructure were, according to Prague council, 868 m CZK during the event in 2002. This amount includes costs of damaged works of arts, library collections, teaching aids and leisure facilities.

The costs were adjusted for the prices in 2013 based on the average annual inflation rate of 2.31%: 1,115.5 m CZK.

The costs were adjusted for particular flow rates. These numbers were calculated as ratios of the original amount and the proportion of area flooded by particular flow rate.

**Table 6.6-13: Avoided cultural costs**

| | Q20 | Q50 | Q100 | Q500 |
|---|---|---|---|---|
| CZK (m) | 567.59 | 792.71 | 982.96 | 1,115.5 |
| EUR (m) | 21.84 | 30.5 | 37.82 | 42.93 |
| % of Q2002 | 51 | 71 | 88 | 100 |

**Avoided environmental costs**

The costs of damaged infrastructure were, according to Prague council, 277 m CZK during the event in 2002. This amount includes costs of damages to natural functions of water streams, damages to migration passableness and ecological stability, other damages to water streams, costs of soil decontamination and of the decontamination of surface and underground water.

The costs were adjusted for the prices in 2013 based on the average annual inflation rate of 2.31%: 355 m CZK.

The costs were adjusted for particular flow rates. These numbers were calculated as ratios of the original amount and the proportion of area flooded by particular flow rate.

**Table 6.6-14: Avoided environmental costs**

| | Q20 | Q50 | Q100 | Q500 |
|---|---|---|---|---|
| CZK (m) | 430.15 | 468.5 | 509.93 | 355 |
| EUR (m) | 16.55 | 18.03 | 19.62 | 13.66 |
| % of Q2002 | 121 | 132 | 144 | 100 |

## 6.7 Copenhagen

Andreas Hastrup Clemmensen, Anne Haugvaldstad, DBT

**Introduction**

In the spring of 2010, the City of Copenhagen decided to investigate opportunities and consequences of climate adaptation against flooding, as a part of their background material to form the basis of the future work for a comprehensive climate strategy and a detailed climate adaptation plan. The report was written by the consultancy firm COWI, which divided the consequences of flooding into flooding from storm-surge and flooding from extreme rainfall events where the sewer system capacity is exceeded[52].

Risk maps were developed for the municipality in which the entire municipality was divided into 100x100 meter cells. The risk was calculated in DKK, based on a weighing of the probability of flooding and the damage costs associated with the flooded areas. In addition, the optimum time for protecting Copenhagen from storm-surge with a dike was calculated based on an economical risk assessment and a cost-benefit analysis over a 100 year period.

**Flooding from sea-water**

The extent and consequence of various high tide levels for the current situation and for the next 100 years with the expected climate and sea-level conditions has been investigated. The expected climate and sea-level conditions are based on the IPCSS SRES A2 scenario, which is downscaled to the local area in question. Under this scenario, sea-levels around Copenhagen are expected to rise 1 meter from 1990 to 2100. High tides will be a little more extreme in the rare events, for example, a 100-year high tide will be 10 cm higher than today, in addition to the general sea-level rise.

Storm-surges can lead to high waters and flooding in Copenhagen. In the table below it can be seen that high water levels are expected to reach a higher level above the sea-surface more often, this can potentially cause more serious flooding in the future. The surface of the sea is defined in this context as the basis of the national height system DVR90 (Danish Vertical Reference 1990), which is used as standard reference for heights above mean sea level in Denmark DVR90. The studies are performed using a method of calculation that takes account of how the high water builds up and falls again and the way in which the water will flow over land[53].

**Table 6.7-1: Storm-surge events compared to 1990 baseline levels**

| Water level (DVR90) | Year 2010 | Year 2060 | Year 2110 |
|---|---|---|---|
| 20-year flood event | 139 cm | 180 cm | 233 cm |
| 50-year flood event | 151 cm | 194 cm | 247 cm |
| 100-year flood event | 160 cm | 205 cm | 263 cm |

Note: High tide is measured by the national height system DVR90 (compared to the baseline 1990).

[52] Copenhagen Climate Adaptation Plan, 2010

[53] COWI, Opportunities and consequences of adaptating Copenhagen to flooding, 2011

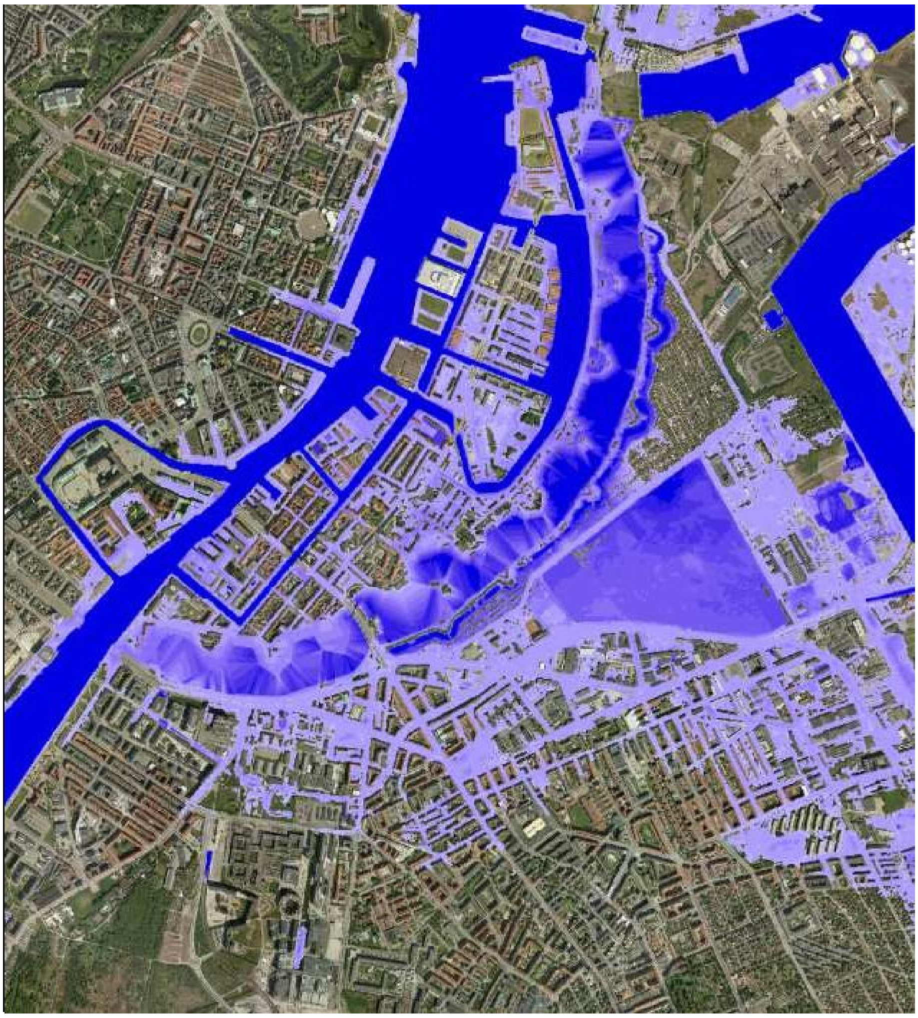


**Figure 6.7-1: Maximum propagation of a high tide of 226 cm (DVR90)**
Note: This corresponds to an expected 11-year high tide as it will look in 2110.

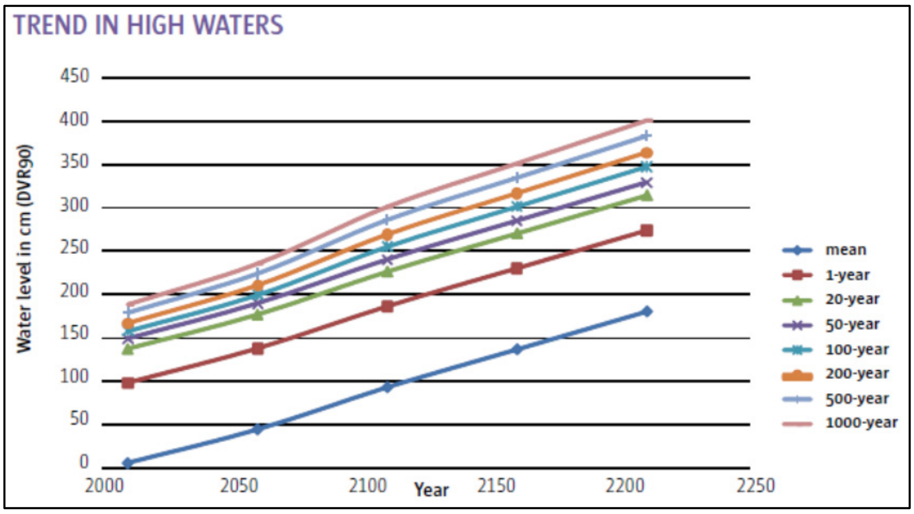



**Figure 6.7-2: Expected development in high waters and water levels as a result of storm surges**

The figure above shows the expected development in high waters and water levels as a result of storm surges. The figure shows that high waters levels which occur rarely today will occur far more frequently in the future. For example a 160 cm high water level only occurs every 100 years today, while a high water level of 180 cm will occur every 20 years in 2060.

**Flooding from rainwater**

The magnitude and impact of different predicted extreme rainfall events is investigated from today and until 2110. Extreme rain is defined as rain that exceeds the capacity of the sewer systems' dimensions. The table below shows the maximum extent of flooded area from projected extreme rainfall events. The results show a large increase in the flooded area between a 20-year event in 2010 compared with a 100-year event in 2010 and 20-year event in 2110.

**Table 6.7-2: Maximum extent of flooded area from extreme rainfall events**

| Frequency | Year | Flooded area (Total ha.) | Copenhagen (ha.) | Christianshavn (ha.) | Amager (ha.) |
|---|---|---|---|---|---|
| 20-year | 2010 | 230 | 162 | 2 | 67 |
| 100-year | 2010 | 595 | 492 | 2 | 101 |
| 20-year | 2110 | 595 | 492 | 2 | 101 |
| 100-year | 2110 | 742 | 554 | 2 | 184 |

The flooded area includes all surfaces where the water is higher than 3 mm.

The map shows for each rain event, the maximum propagation of the flood during the course of events and the maximum water depths occurring in the flooded areas. Note that the model results show that a large portion of the rainwater will be collected in the hollows by Lyngbyvej and Lersø Avenue. This was also the case when a real cloudburst event occurred in August 2010, which corresponded to a 100-year rain event.

**Figure 6.7-3: Detailed map showing the extent of flooding from a 100-year extreme rainfall event in 2110**

**Step 1 - Risk assessment**

**Storm-surge**

Damage costs as a consequence of predicted storm-surge events are calculated in the areas affected by flooding from seawater and the maximum depth in the affected areas. In addition to the direct damage costs the indirect costs associated with lost work hours/production etc. are included. The table below shows the socio-economic damage-costs associated with single storm-surge events without mitigation. The damage costs are used to assess the socio-economic consequences for the baseline option (no new coastal protection, only maintenance of existing protection).

**Table 6.7-3: Damage costs in case of storm-surge events**

| High tide (DVR90) | Frequency | Year | Total costs m DKK |
|---|---|---|---|
| 139 cm | 16 year | 2010 | 0 |
| 158 cm | 85 year | 2010 | 465 |
| 200 cm | 73 year | 2060 | 1,576 |
| 226 cm | 11 year | 2110 | 4,647 |
| 225 cm | 70 year | 2110 | 9,287 |
| 285 cm | 300 year | 2110 | 13,583 |

The damage is primarily associated with the flooding of ground buildings and buildings with basements. The scope of the flooding of ground floors, basements and shops is calculated based on data from the Building and Dwelling Register. With sea-level rises the traffic is also affected, the estimated delay due to a storm-surge event is 242,000 hours.

The damages are priced with a set of socio-economic unit price from earlier studies. The unit and $m^2$ price can be seen in the table below calculated in factor prices. These prices have been regulated by 10%.

**Table 6.7-4: Socio-economic costs in case of storm-surge event**

| Damages | Unit | Price (DKK/ m2) | Price (DKK/Unit) |
|---|---|---|---|
| Traffic Disturbances all highways | Unit | 0 | 363 |
| Road fracture | Unit | 0 | 1,100,000 |
| Ground Floor | $m^2$ | 5,973 | 0 |
| basement | $m^2$ | 352 | 0 |
| Substations | Unit | 0 | 1,100,000 |
| Power shortage - private (> 5 h) | Unit | 0 | 1,850 |
| Power shortage – businesses (> 5 h) | Unit | 0 | 5,551 |
| Power shortage - public | Unit | 0 | 0 |
| Shops – production loss | Unit | 0 | 0 |
| Shops – Compensation of stock - basement | $m^2$ | 2,328 | 0 |
| Shops - Compensation of stock - Ground floor | $m^2$ | 2,328 | 0 |
| Shops, compensation costs – Ground floor | $m^2$ | 3,121 | 0 |
| Damage on sewers | Unit | 0 | 1,100,000 |
| Stations, seawater | Unit | 0 | 228,788,185 |

Note: Unit prices of damage by sea-water rise.
Source: COWI, Opportunities and consequences of adapting Copenhagen to flooding, 2011.

### Cloudbursts

The investigation of extreme cloudburst has covered the entire city of Copenhagen and adjacent areas, which have an importance for the flooding in the municipality from upstream areas. It is chosen to assess 4 alternative approaches a part from the reference, where no adaptation action is taken. During extreme rainfall events basements are primarily affected.

The table below shows the socio-economic costs with single events from cloudbursts without mitigation, calculated in factor prices.

**Table 6.7-5: Socio-economic costs from cloudbursts without mitigation**

| Intensity (cm) | Frequency | Year | Total costs (M DKK) |
|---|---|---|---|
| 47.1 | 20 year | 2010 | 2,039 |
| 62.4 | 100 year | 2010 | 4,548 |
| 62.6 | 20 year | 2110 | 4,548 |
| 87.3 | 100 year | 2110 | 5,625 |

The table below shows the damage costs for rainwater in factor prices if no action is taken. The results show that the total damage costs of a 100-year event in 2110 are 5,625 m DKK.

**Table 6.7-6: Damage costs for rainwater in factor prices**

| Measured in m DKK | Sewage today | 20/2020 | 100/2010 20/2110 | 100/2110 |
|---|---|---|---|---|
| Traffic Disturbances all highways | 0 | 9 | 35 | 53 |
| Road fracture | 0 | 11 | 22 | 33 |
| Ground Floor | 397 | 368 | 1,274 | 1,700 |
| basement | 0 | 641 | 1,045 | 1,181 |
| Substations | 0 | 28 | 66 | 77 |
| Power shortage - private (> 5 h) | 0 | 0 | 2 | 3 |
| Power shortage – businesses (> 5 h) | 0 | 2 | 9 | 11 |
| Power shortage - public | 0 | 0 | 0 | 0 |
| Shops – production loss | 245 | 0 | 0 | 0 |
| Shops – Compensation of stock-Basement | 0 | 748 | 1,493 | 1,734 |
| Shops - Compensation of stock - Ground floor | 0 | 205 | 528 | 741 |
| Shops, compensation costs – Ground floor | 0 | 15 | 28 | 39 |
| Damage on sewers | 0 | 6 | 17 | 22 |
| Stations, seawater | 0 | 0 | 0 | 0 |
| Stations, rainwater 47,1 | 0 | 7 | 0 | 0 |
| Stations, rainwater 61,2 | 0 | 0 | 29 | 0 |
| Stations, rainwater 87,4 | 0 | 0 | 0 | 31 |
| **Total** | **0** | **2,039** | **4,578** | **5,625** |

To support the prioritization of climate adaptation measures economic risk assessments for seawater and rainwater have been calculated. The risk is calculated as the total probability for flooding multiplied by the damage costs connected with the expected damages the flooding will cause. In other words Risk = probability * consequence. The risk of flooding from the sea and rain over a 100-year period is visualized on maps over the municipality by dividing the municipality into 100 x 100 meter cells. This is done under the assumption that nothing will be done to mitigate the expected trend in sea-level rise and storm-surge. The economic risk is calculated for each of the 100*100 cells for each year and for the total 100-year period 2010-2100. The areas with the greatest probability and greatest costs have the greatest risk (red colour), while areas with great probability but where the damage costs are minimal (parks etc.) a low risk is specified (yellow or no colour).

The figure below shows the development of the yearly economic risk from seawater (blue) and rainwater (red) with no mitigation. The yearly risk in DKK is the probability multiplied by damage costs.

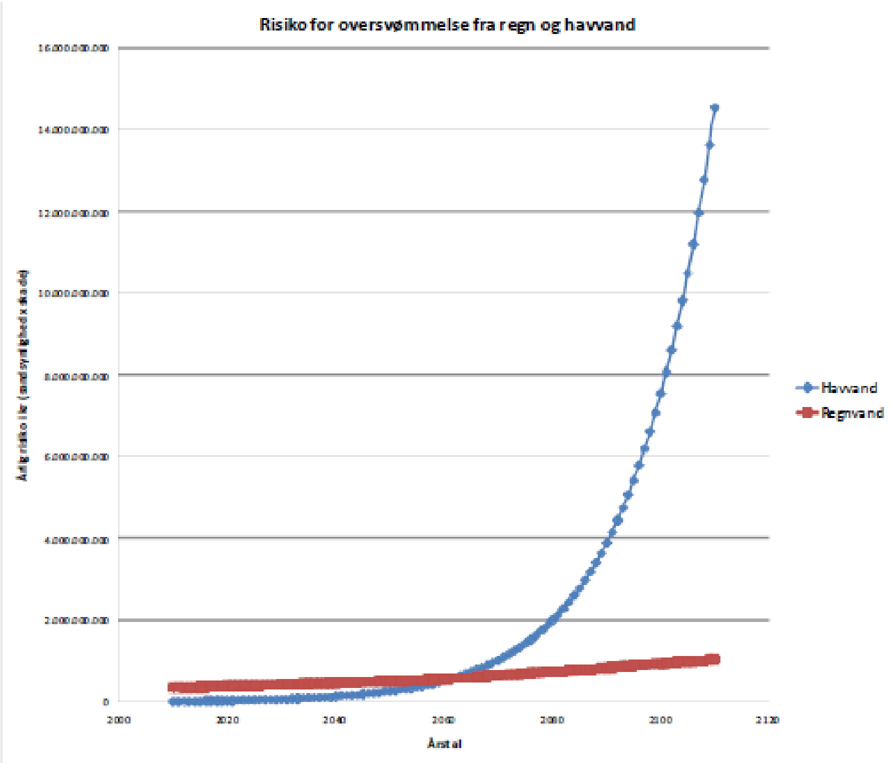



**Figure 6.7-4: Development of the yearly economic risk from seawater and rainwater with no mitigation**
Notes: Seawater: blue line; rainwater: red line

**Cost Benefit Analysis**

The aim of the socio-economic screening analysis is to quantify the benefits and costs of climate change by storm-surge and cloudburst events in Copenhagen. The results from the CBA express the sum of the negative and positive consequences of the proposed adaptation measures. It is important to note that regarding the costs on the environment, there are elements, which are not included in the analysis.

- Cloudburst
- Storm-surge

**Step 2 - Potential measures and results**

**Storm-surge**

A comprehensive analysis of the socio-economic costs for the baseline option (business-as-usual) to protect Copenhagen from the rising sea-levels the next 100 years are compared with the implementation and operation costs of the adaptation measures, which can mitigate some of the flooding which otherwise will occur. The table below shows net current gain of the damage costs and possible adaptation calculated in m DKK.

**Table 6.7-7: Net current gain of the damage costs and possible adaptation**

| | |
|---|---|
| Net present value of adaptation measures | 19,908 |
| Net present value of costs | 3,997 |
| **Net present value** | **15,911** |

The adaptation solutions considered are designed to withstand a high tide of 255 cm (measured through the DVR90 model). 2.55 m corresponds to a 70-year high tide in 2110, and it is highly unlikely (less than 1/1000) that a storm-surge of that magnitude could occur today (see figure “development of high waters”). The port can withstand a future SLR of 1-1.4 m above the present level, however, there are certain low-lying areas that are likely to be flooded at this development. This applies, for example, to large parts of Christianshavn. On the basis of the risk assessment, the municipality of Copenhagen has pointed out that it would be most appropriate to close the port in the north and in the south by establishing dikes and sluices, along with levees, elevated wharfs and other targeted measures for low lying areas (Amager east, etc.).

**Dike and sluices in the northern port: *Kronløbet* and *Lynetteløbet***

In the following section a description of the solution, which is considered to be the most relevant, on the basis of technical, safety and economic aspects. It should be noted that the described possible solutions are based on an overall assessment and general experience with sluices and levees.

The main port inlet, Kroløbet and Lynetteløbet is protected with sluices. In the south a sluice is placed in a new established dike south of Kalvebod Bridge. These sluices, in combination with the new established dikes, elevated quay etc. by the eastcoast of Amager, protect the Copenhagen area, the Nordhavn area, Amager and the areas by Kalvebod against a stormsurge event at 2.55 m DVR90.

In the closing of the northern port inlet by Kronløbet and Lynetteløbet the technical solutions are limited due to the requirements that the port main inlet has an approx. 150 m free width with no obstructions. The proposed solution includes port flaps with retractable gate valves, similar to the project "Moses" underway in Venice.

The closing of the Copenhagen harbour is expected to occur less frequently than in Venice, however the requirements for the establishment of the closure will be the same in terms of time and safety. When a storm-surge event I warned the closing of the port will occur during the warning time, which is estimated from 12 to 20 hours.

The illustration displayed below, shows a cross-section of the "Moses" sluice system, modified to a water depth of 10 m, which is the water depth in *Kronløbet*. The system consists of the following main elements:

- A concrete structure immersed in the sea bed with the upper side in level with this. The construction is carried out as pre-cast concrete sections placed on prepared stone pillows.
- Closing flaps are designed as hollow steel doors that revolve around the horizontal axles. When closed, the ports are embodied in the concrete structure, so that average sailing depth is 10 m.
- Concrete structures on each side of the inlet. These are in close connection with to the breakwaters.

During situation of storm-surge warning air is blown into the inlet chambers so the port valves rotate and are position approximately 30 degrees vertical. The inlet is closed for water inflow as all connections are tight. The "Moses" system is responsive and flexible in regards of high water levels as port flaps can be raised in a few hours and at different angles depending on the sea level heights.

Lynetteløbet’s width, of approx. 50 meters, is also proposed to be closed by the same system with port valves. Both Kronløbet and Lynetteløbet should be closed simultaneously and similar systems would be beneficial both financially and in regards to the operational conditions.

Below is a sketch of the system with the port valves raised in the closed position.

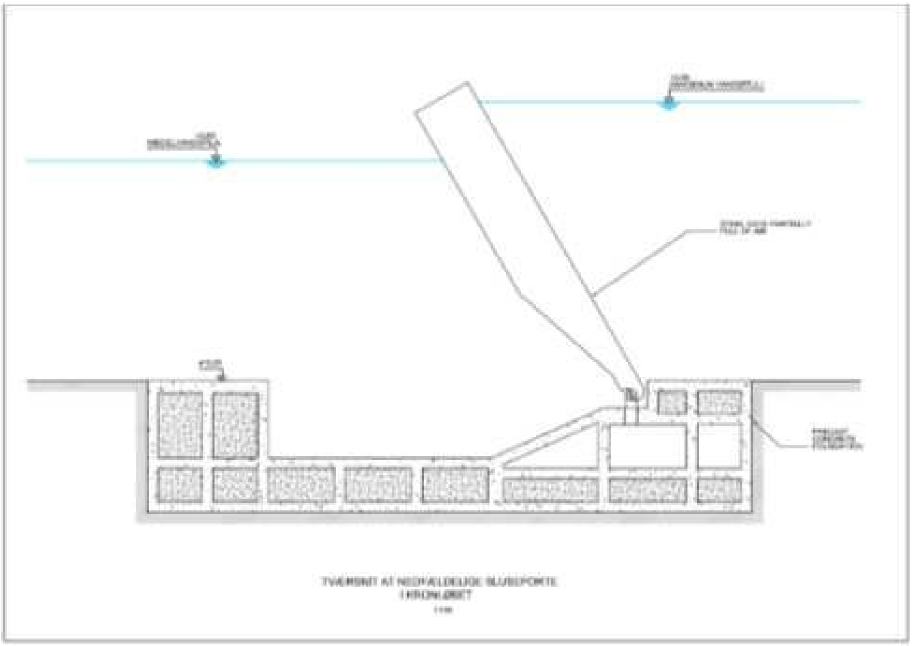


**Figure 6.7-5: Sketch of hydraulic port valves**

The protection solution offers recreational potential. The solution can potentially be implemented as a recreational area.

**Figure 6.7-6: Examples of the dike with the 'moses model' sluices**

In the table below the market prices are shown for the proposed dike solutions and sluices in the north, south and Amager are shown. The market prices include the investment costs, life expectancy, operation and maintenance costs and reinvestments costs in m DKK. The market prices mean the costs are not corrected for tax distortion loss and net tax factor.

**Table 6.7-8: Construction and operation costs for possible actions against sea-level rise, market prices in m DKK**

| Location and measure | Investment costs (m DKK) | Life expectancy (year) | Operation and maintenance costs (m DKK) | Reinvestment costs (m DKK) |
|---|---|---|---|---|
| North | | | | |
| Inlet closes w/flaps | 1,300 | 50 | 10 | 600 |
| Dam | 300 | 100 | 2 | 20 |
| Navigation canal, beach etc. | 100 | 100 | 2 | 10 |
| South | | | | |
| Sluices (2 pcs. Of 100 m DKK) | 200 | 50 | 3 | 150 |
| Dam | 50 | 100 | 1 | 30 |
| Miscellaneous (temp. dam etc.) | 50 | 0 | 0 | 0 |
| Along Amager | | | | |
| Dikes/dams/spun etc. | 300 | 80 | 6 | 0 |
| **Total** | **2,300** | **0** | **24** | **810** |

Source: COWI

By converting the investment process to present value and corresponding risk (costs) for each year for the completion of the dike a graph illustrates the gain in present value depending on the year of the start of the investment/completion of the dike. The x-axis refers to the start of the investment, assuming a construction time of 5 years. From a purely economic assessment 2035 appears to be the optimal year to start the investment, whereas the dike will be finished in 2040. If the dike is constructed relatively fast there will be a net gain of approximately 6 bn DKK in present value looking over a 100-year time period. Damage costs exceed the cost of implementation.

**Cloudbursts**

A comprehensive assessment of the societal costs connected protection against cloudburst is made.

The analysis shows the 5 adaptation options. For the baseline option it is assumed that no further investment in upgrading the sewers, or other ‘surface’ adaptation actions are made.

1. Maintain sewage service level
2. Maintain sewage service level plus backflow valve in all basements
3. Maintain sewage service level plus backflow valve in all basements plus surface adaptation
4. Only backflow valve in all basements plus surface adaptation
5. Only backflow valve plus surface adaptation after the sewage system is upgraded

**Table 6.7-9: The five options for adaptaing to cloudburst**

| Assessment type | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 |
|---|---|---|---|---|---|
| Damage costs in basic situation | 15,552 | 15,552 | 15,552 | 15,552 | 5,458 |
| Damage costs | 5,458 | 2,471 | 1,785 | 4,316 | 1,785 |
| Benefits (reduction of damage costs compared to baseline | 10,094 | 13,081 | 13,767 | 11,236 | 3,673 |
| Measures | 10,372 | 11,108 | 13,374 | 3,001 | 3,001 |
| Net present value | -278 | 1,973 | 394 | 8,235 | 672 |

In option 1 the results show that the net present value by maintaining the current service levels is -278 m DKK. There is a large gain in scenario 2 compared to scenario 1, where backflow valves are installed. In scenario 3 an additional measure is taken by surface adaptation. By comparing scenario 2 and 3, there is a large benefit in installing backflow vales.

If the sewer system is not extended and the adaptation measures only include the installation of backwater valves, protection of basements and other surface measures, a net present value of 8 bn DKK is achieved. However, it is not realistic to not improve the existing sewer system, which is the case in scenario 4.

In scenario 5 it is assumed that the reference service level is maintained which means the implementation costs do not include an extension of the sewer system. A net present profit of approximately 0.7 bn DKK is calculated if adaptation measures are made.

**Step 3 - Evaluation approach**

The socio-economic analysis presented here aims to quantify the costs and benefits of climate impacts of sea level rise and extreme rain in Copenhagen. The following section will outline the major methodological choices, which this analysis is based on.

Evaluation of the adaptation interventions overall profitability, depends on the value of the socio-economic surplus, relative to a reference point without the measure. A positive overall value indicates that it would be beneficial to society. A negative value indicates the contrary.

However, in the results it is important to notice that certain elements are omitted from the analysis. In particular, three reservations are notable:

- Non-monetised effects
- Uncertainty
- Distributional consequences

In accordance with the Ministry of Finance’s recommendations a tax distortion loss for all net costs is included in the analysis. Tax distortion loss is set at 20% in accordance with the recommendation of the Ministry. To express production goods marginal value, the productivity in a price range that reflects the market price and thus the willingness to pay for the resulting products

Market prices are used in the analysis and in order to reflect market prices and the willingness to pay for the resulting products, purchase prices are increased by an average net tax factor. This expresses the average tax burden found in consumer products. Newer public guidelines recommend the use of a 35% net tax factor, but there is considerable disagreement about this rate. The transportation area operates with a net tax factor rate of 17%, which is the ‘old’ rate from the Ministry of Finance’s existing guidance. 17% is used in this report.

**Step 4 - Data Collection**

The table below summarizes the key assumptions used in the CBA.

**Table 6.7-10: Key assumptions for CBA**

| Parameters | Value/conditions |
|---|---|
| Basic method | Price base method based on social principles |
| Timeframe | 2110 |
| Discount rate | 3% |
| Net Tax rate | 17% |
| Tax Discount rate | 20% |
| Geographical boundaries | Denmark |
| Price level | 2010-prices |

A discount rate is used to convert the values, which decline over time with an annual value. The discount rate is determined by the Ministry of Finance. The latest official rate is 6%. Socio-economic analyses on climate change often consider very long time horizons of 50 or 100 years. Using a high discount rate in these circumstances means that the present value of future investments becomes very small. Therefore, damage costs that occur in the latter part of the century, almost does not count in the equation. For this analysis it was consequently decided to use a discount rate of 3%.

**Unit prices**

The damage is priced with a set of socio-economic unit prices (DKK/unit) from a previous study. These have been subject to price regulation by 10%.

**Table 6.7-11: Unit prices - damage by seawater rise**

| Damages | Unit | Price (DKK/m$^2$) | Price (DKK/unit) |
|---|---|---|---|
| Traffic Disturbances all main roads | Unit | 0 | 363 |
| Road damages | Unit | 0 | 1,100,000 |
| Ground Floor | m$^2$ | 5,973 | 0 |
| Basements | m$^2$ | 352 | 0 |
| Substations | Unit | 0 | 1,100,000 |
| Power failures private (> 5 h) | Unit | 0 | 1,850 |
| Power failures businesses (> 5 h) | Unit | 0 | 5,551 |
| Power failures public (> 5 h) | Unit | 0 | 0 |
| Shops - production loss | Unit | 0 | 0 |
| Shops – inventory costs basement | m$^2$ | 2,328 | 0 |
| Shops – inventory costs ground floor | m$^2$ | 2,328 | 0 |
| Shops – renovating costs ground floor | m$^2$ | 3,121 | 0 |
| Damages on sewers | Unit | 0 | 1,100,000 |
| Stations, seawater | Unit | 0 | 228,788,185 |

Source: Report to the EPA "Climate Change Adaptation of drainage systems and method of testing. Economic analysis 2007"

The 1,168 rooms in the detached houses, which are flooded at level 285 are priced by DKK 550,000 per unit. This gives a total cost of 642 m DKK for flooded living rooms. This price is now seen in relation to the number of square meters, and we thereby obtain an m2 cost of living rooms at 5,593 DKK/m2. The same calculations have been done for basements, which results in a cost of 352 DKK/m2.

**Storm-surge**

The damages inflicted by seawater to buildings and to the infrastructure are extensive. Six levels of sea water rise (in centimetres) have been chosen for the analysis, 137, 158, 200 226 255 and 285. For each of these elevations the damages costs are calculated. The level of damages is primarily concerned with living rooms and basements in the Copenhagen, calculated by using the public "BBR" register. The BBR register contains a number of categories. In this model some main categories are chosen covering approx. 95% of the flooding.

It is evident from the table below, that the number of flooded living rooms and basements (m2) are dramatically increased with each elevation level.

**Table 6.7-12: Expected damages for selected storm surge water heights above 1990**

| | | Storm surge water heights above 1990 levels (cm) | | | | | |
|---|---|---|---|---|---|---|---|
| **Damage** | **Unit** | **137** | **158** | **220** | **226** | **255** | **285** |
| Traffic Disturbances all main-roads | Citizens delay in hours | 0 | 0 | 60,500 | 242,000 | 242,000 | 242,000 |
| Road damages | Number | 0 | 0 | 1 | 2 | 4 | 9 |
| Ground Floor | Flooded $m^2$ | 0 | 25,999 | 110,147 | 337,770 | 748,076 | 1,179,501 |
| Basements | Flooded $m^2$ | 0 | 10,033 | 127,991 | 390,435 | 724,938 | 1,025,561 |
| Substations | Number of substations as damaged and repaired | 0 | 10 | 20 | 60 | 114 | 185 |
| Power failures private (> 5 h) | Number of houses / people without electricity for 5 days | 0 | 30 | 371 | 1190 | 1977 | 3,589 |
| Power failures businesses (> 5 h) | Number of businesses without electricity for 5 days | 0 | 91 | 543 | 1504 | 2643 | 3,517 |
| Power failures public (> 5 h) | Number of institutions without electricity for 5 days | 0 | 0 | 0 | 0 | 0 | 0 |
| Shops - production loss | Flooded m2 | 0 | 0 | 0 | 0 | 0 | 0 |
| Shops – inventories, basement | Flooded m2 | 0 | 43,254 | 165,978 | 348,869 | 559,942 | 718,825 |
| Shops - inventories, ground floor | Flooded m2 | 0 | 80,341 | 168,064 | 570,637 | 1,117,615 | 1,560,859 |
| Shops – renovating ground floor | Flooded m2 | 0 | 2,279 | 13,274 | 28,600 | 56,777 | 94,484 |
| Damages on sewers | Number | 0 | 0 | 5 | 11 | 15 | 17 |
| Stations, seawater | Number | 0 | 0 | 0 | 0.4 | 1 | 1 |

Seawater surges also affect traffic. According to traffic counts undertaken by the Copenhagen Municipality's Centre for Traffic 290,400 cars crossed the lake section in 2007. It is assumed that there is one person using a car and each car is delayed for 10 minutes per day for 5 days. The total delay for all citizens will be 242.000 hours.

**Cloudburst**

Four alternatives in addition to the reference baseline were nothing is done, has been looked at, to evaluate the damage costs caused by cloudbursts. The four options are:

1. Maintain sewage service level
2. Maintain sewage service level plus backflow valve in all basements
3. Maintain sewage service level plus backflow valve in all basements plus surface adaptation
4. Lowering the level of services (no sewer expansion), only backflow valves in basements plus surface adaptation

**Table 6.7-13: Damages by extreme rain**

| Frequency, years | Unit | 20/2010 | 100/2010 20/2110 | 100/2110 |
|---|---|---|---|---|
| Traffic disturbances all main roads | Citizens delays in hours | 24,200 | 96,800 | 145,200 |
| Road damages | Unit | 10 | 20 | 30 |
| Ground Floor | Flooded $m^2$ | 61,615 | 213 305 | 284 676 |
| Basements | Flooded $m^2$ | 1819.015 | 2965.571 | 3350.850 |
| Substations | Number, damaged and repaired | 25 | 60 | 70 |
| Power failures private (> 5 h) | Unit | 261 | 1,172 | 1,644 |
| Power failures businesses (> 5 h) | Unit | 303 | 1,599 | 1,912 |
| Power failures public (> 5 h) | Unit | 0 | 0 | 0 |
| Shops - production loss | Unit | 0 | 0 | 0 |
| Shops – inventory costs basement | Unit | 321 403 | 641 303 | 745 035 |
| Shops – inventory costs ground floor | Flooded $m^2$ | 88,289 | 226 691 | 318 557 |
| Shops – renovating costs ground floor | Flooded $m^2$ | 4,667 | 9,123 | 12,346 |
| Damages on sewers | Unit | 5 | 15 | 20 |
| Stations, rainwater (frequency/years) 20/2010 | Unit | 1 | 0 | 0 |
| Stations 100/2010 | Unit | 0 | 1 | 0 |
| Stations 100/2110 | Unit | 0 | 0 | 1 |

Source: Data for basements and living rooms are received from BBR.

Regarding the level of damage, it is seen that it is primarily basements that are affected by cloudbursts. On the basis of the model, it has been possible to give an estimate of the number of road disturbances, sewers, disruption of services and the number of stations affected by cloudbursts.

The number of living rooms and basements that have been affected are calculated form BBR. The table below specifies the water depth from the building base where damage occurs.

**Table 6.7-14: Water level and damage incurred in apartments and basements**

| Apartments with basement | Damage, when water depth is greater than (cm) |
|---|---|
| Water in the basement from surface water (not from sewer) | 15 |
| Water penetrates and destroys ground floor | 50 |
| *Apartments without a basement:* | |
| Water penetrates and destroys ground floor | 30 |
| *Detached houses with basement:* | |
| Water in the basement from surface water (not from sewer) | 10 |
| Water penetrates and destroys ground floor | 30 |
| Detached houses without a basement: | |
| Water penetrates and destroys ground flood | 20 |

To assess the number of hours affected by traffic disturbance the same method as for storm surge was used. A 0.17 hours delay per car was assumed. It is considered that rain water will cause delays for one day. It is estimated, that for a 20-year event in 2010 there will be 24.200 hours of delay and 145,200 cars affected, while for a 100 year-event in 2110 there will be 145.200 hours of delay and 871,200 cars affected.

**Step 5 – Evaluation and Prioritisation**

**Sensitivity analysis**

The results are subject to uncertainties, which is why a sensitivity analysis is made. Sensitivity analyses are calculated for sea-level rise and cloudbursts.

**Sea-level rise**

The results from the sensitivity analysis of the net-gain for sea-level rise in m DKK are show in the table below. It is assumed that the flood frequency is every two years. Overall the results show that the chosen parameters influence the magnitude of the net-gain. The reference here is a situation where dikes and sluices are installed, with the unit prices, costs and discount rate described.

**Table 6.7-15: Sensitivity analysis of the net-gain for sea-level rise**

| Parameter | M DKK Net gain |
|---|---|
| Reference | 6,429 |
| Unit price + 50% | 11,642 |
| Unit price – 50% | 1,216 |
| Initiative costs + 50% | 4,430 |
| Initiative costs - 50% | 7,028 |
| Discount rate 1% | 37,035 |
| Discount rate 6% | -1,061 |
| Discount rate 6%, unit price -50% | -2,087 |

The sensitivity analysis is conducted with a discount rate of 1 % and 6% because the calculations are over a 100-year period, meaning they are very sensitivity to the chosen discount rate. The conclusion is that the results are very sensitive to the discount rate. If the discount rate is 1% instead of 3%, will give a socio-economic benefit of approximately 37 bn DKK, which means there is an extremely high financial benefit of eliminating the damages of a 100-year event. This is primarily due to the fact that the damage costs will weigh more in the calculations, which are spread out over 100 years. A discount rate set to 6% will results in a negative net-gain of approximately 1 bn DKK.

The conclusion is that climate adaptation in terms of storm-surge protection is affected by the discount rate factor. There will be a socio-economic benefit of a discount rate set to 1%, 3% and 6%.

If the unit prices increases the damage costs will increase and vice versa. The sensitivity analysis is therefore conducted with a 50% price increase and a 50% price decrease. The conclusion is that regardless of whether the unit prices rise or fall, there will be socio-economic benefits of climate adaptation in terms of storm-surge protection.

A sensitivity analysis is conducted on the costs of potential initiatives. The prices are varied with +/- 50%. There is only a slight variation in the net-gain because the costs of possible actions is only approximately 20% of the damage is costs. There will therefore always be a net-gain with climate adaptation.

If we assume a discount rate of 6% and a 50% price increase a negative socio-economic gain will occur because the damage costs will be 1,583 m DKK and the potential initiative costs is 3,122 m DKK meaning a socio-economic loss will occur.

**Cloud-burst**

The net gain for the sensitivity analysis from cloudburst in m DKK is shown in the table below.

**Table 6.7-16: Sensitivity analysis of the net-gain for cloudburst**

| Parameter | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 |
|---|---|---|---|---|---|
| Reference | -278 | 1,973 | 394 | 8,235 | 672 |
| Unit price + 50% | 4,769 | 8,513 | 7,277 | 13,853 | 2,508 |
| Unit price – 50% | -5,325 | -4,566 | -6,490 | 2,617 | -1.165 |
| Initiative costs + 50% | -5,464 | -3,580 | -6,293 | 6,734 | -829 |
| Initiative costs - 50% | 1,278 | 3,640 | 2,400 | 8,685 | 1,122 |
| Discount rate 1% | 8,039 | 14,025 | 12,441 | 21,876 | 4,401 |
| Discount rate 6% | -2,136 | -1,264 | -2,469 | 3,182 | -333 |
| Discount rate 6%, unit price -50% | -4,487 | -4,293 | -5,643 | 602 | -1,156 |

The sensitivity analysis is conducted with a discount rate of 1 % and 6% because the calculations are over 100-year period, meaning they are very sensitivity to the chosen discount rate. If the 6% discount rate is chosen there will be a socio-economic loss in scenario 1, 2, 3 and 5, there will be profit for scenario 4. If a 1% discount rate is chosen, there is a socio-economic benefit in all scenarios.

There will be an economic benefit for all the scenarios if the unit price increases by 50%. If the unit price increases by 15% the damage costs will be a lot greater, this will result in a socio-economic benefit.

If the initiative costs decreases by 50% there will be a benefit connected with all scenarios. If the initiative costs increases by 50% scenario 4 will be the only scenario which is socio-economic profitable. A sensitivity analysis by combining a high discount rate and low unit prices results in all scenarios being unprofitable for society.

**Storm-surge MCA**

**Introduction**

The main climatic threats to the city of Copenhagen are induced by water, which is reflected in the two pillars of the adaptation strategy, namely cloudburst and storm-surge. Where the work on cloudburst has progressed, there is still uncertainty about the economic aspects concerning the various adaptation options to counter the threat from sea-level rise and storm-surges. The economic focus in the Copenhagen case is therefore on the potential impacts, costs and benefits of different adaptation options to storm-surges. There are currently no political decisions made regarding storm-surge protection, which is why the Danish Board of Technology and Copenhagen Municipality have taken the initiative to organize events regarding different aspects for storm surge protection.

To highlight the most important aspects of the future work with storm surge protection three events have proceeded with presentations from experts, debates and participatory methods. The focus of the first event was on climate data and the knowledge base for the future work with storm surge adaptation (4th of February 2014). The main goal was to recognize current knowledge about future sea level rise and storm surge, as well as to discuss the further development of the knowledge in terms of work on flood protection in the Copenhagen area. Presentations were held by the consultancy firm COWI, the Danish Metrology Institute and the Danish Coastal Authority, followed by a discussion. COWI explained how the Climate Adaptation Plan for Copenhagen was developed, including a description of the used sea-level statistics, modelling of consequences, socio-economic impact and risk and sensitivity analysis. The Danish Metrology Institute explained the expected sea-level changes the next 100 years, IPCC scenarios, risk assessment and the consequence of storm surges. The Danish Coastal Authority described possible consequences of storm-surge events, risk assessment, which is the total probability, sensitivity and risk and possible adaptation measures. The presentations were followed by a discussion.

The second event identified the challenges and possibilities regarding financing storm surge protection (25th of April 2014). Presentations were given by the Danish Coastal Authority, the interest group and member authority of Danish Municipalities Local Government Denmark, the law partnership company Horten, and the Dutch research institute Deltares, followed by group discussions. The key points from the group discussions included that climate change exceeds the costs that municipalities and landowners are able to pay. There are challenges regarding the existing coastal protection law, flooding threated areas, responsibility and finance regarding the current coastal law. The importance of a new financial model, as taxes cannot cover the implementation of the necessary adaptation solutions. Furthermore, there is a lack of incentive to initiate storm-surge adaptation measures.

The third event was (8th of October) about assessing and concretizing future storm surge protection solutions for Copenhagen.

**Workshop on storm-surge solutions for Copenhagen**

Large areas in Copenhagen are threatened by flooding as a consequence of storm surge events. The map below shows the flooding extent of a 2.6 meter storm-surge event (above normal 1990 levels), which is the politically agreed minimum protection level.


**Figure 6.7-7: Flooding impact at 2,26m storm-surge**
Source: COWI

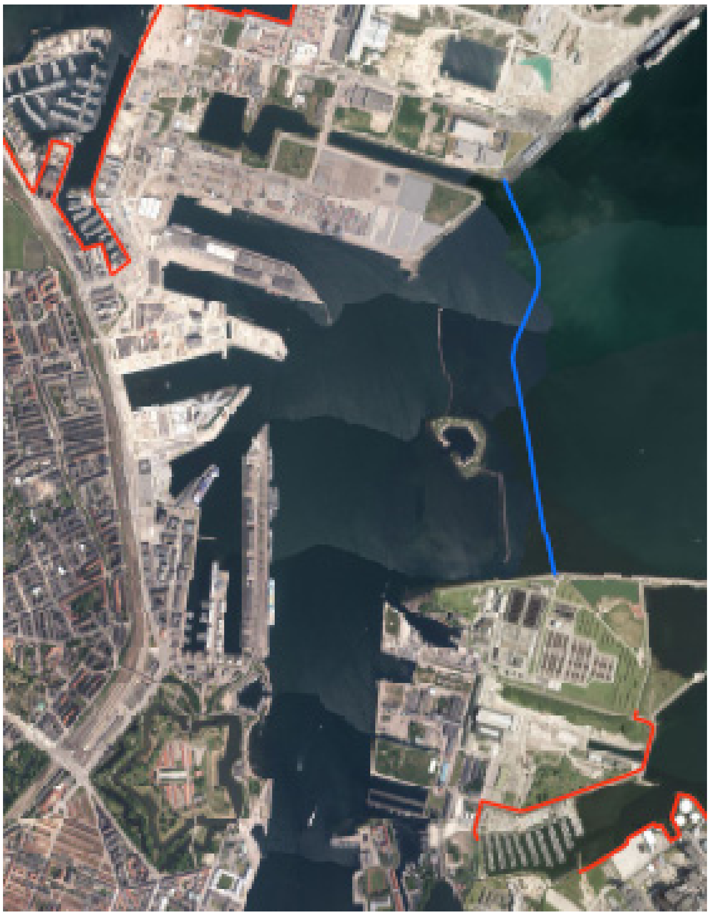


**Figure 6.7-8: Possible dike locations in the northern harbour**

On this basis, the municipality has started investigating opportunities for protecting the city. Based on an assessment report written by COWI the preferred solution will protect the city with dikes, established across the harbour by the Trekroner Island, in the northern inlet to the Copenhagen Harbour, and in the southern inlet by Kalveboderne. Dikes will protect Nordhavn, Svanemølledn and the eastern side of Amager.

As a part of the proposed "outer solution" a dike will be built with sluices in Nordhavn (see map above). This solution has been assessed to be the most economically feasible solution to protect Copenhagen from storm-surge events. This also ensures water flow and navigation during situations with normal water level.  From a purely economic perspective year 2035 is the optimal year to start the investments whereby the dike will be finished in year 2040, hereby assuming a five-year construction period. This perspective is found by calculating the investment process to net present value and calculating the risk process (costs).

The overall purpose of the dike will be to minimize the risk of flooding; however there can also be socio-economic and recreational advantages associated with the solution. If the dike is innovative, integrated and remarkable the solution can achieve national and international attention, thus supporting the city's ambitions to be a climate proof environmental metropolis while being an attractive place to live and invest.

The municipality wants the dike to be incorporated in the overall urban development, by the added value recreational and infrastructural elements in the dike could provide to the city. The third storm-surge workshop held by the Danish Board of Technology involved a wide number of stakeholders, policy makers and private companies to discuss the opportunities and which aspects to include in the dike solution. The invited stakeholders involved 30 of the most relevant actors with respect to future development of Copenhagen Harbour. The participants included employees from the consultancy firms COWI, Rambøll and Niras; the interest organizations CPH City & Port Development, Sund og Bælt, the Danish Architecture Centre; the architecture firms Hasløv og Kjærsgaard Arkitektfirma, Carlberg og Christensen; The Danish Nature Agency; Danish Hydrological Institute; The Danish Society for Nature Conservation; The Danish Coastal Authority; Danish Insurance Association; ATP Properties; The Storm Board; the Metro Company; the Danish Outdoor Council; the property company Refshaleøens Ejendomme, local committee of the Inner City/Christianshavn; municipality workers from Copenhagen, Hvidovre, Gentofte, Tårnby and Dragør Municipality.


**Figure 6.7-9: Stakeholder discussing at MCA workshop**

**Workshop approach and method**

The workshop was developed to receive a range of input from relevant stakeholders in order to improve the municipality's future work with dyke solutions for Copenhagen. The participants worked with three topics at the workshop:

- Rate nine criteria in accordance to what the participants find most important when having to construct a dike solution and generate added value?
- Come up with concrete ideas to how the future dike could be developed, and subsequently rate the accumulated ideas with the nine criteria.
- Develop and describe adaptation approaches to storm-surge and sea-level rise (SLR) in Copenhagen until permanent solutions has been established.

DBT and the Copenhagen Municipality's Climate Unit, under the Technical and Environmental administration, jointly developed the nine criteria to be evaluated, through rating, and subsequently utilised during the workshop. They reflect the wish of the municipality and local politicians to focus on the potential added-value of adaptation solutions. The MCA was served as a tool for stakeholders to assess different adaptation options associated with storm-surge protection. The purpose of the MCA exercise was to receive input (ideas, challenges, possibilities etc.) from important stakeholders. The stakeholders came with suggestions to which innovative/recreational commercial aspects could be integrated in the dike solution. For the MCA exercise the participants were divided into five groups with similar background. This included two groups of people with a technical background (municipal technical workers, engineers etc.), one group with municipality workers, one group with architects and one group with participants who work in various interest organizations.

The nine criteria are perceived as important/relevant to consider in the establishment of a climate adaptation solution (dike). The criteria were grouped into implementation and synergies.

The weighing criteria included:

- *Implementation:* Implementation costs, running and re-investment costs and technical effort (feasibility of construction)

- *Synergy:* Recreational, commercial benefits, tourism, aesthetic focus, environmental concerns, maintaining normal port operation

The participants were presented to the criteria, where a short description of each was given in plenum. The presentation was followed by group discussions at the tables regarding the importance/relevance of the criteria when the establishment of a climate adaptation solution specifically a dike. Thereafter, the participants individually weighed the importance/relevance of the criteria in terms of establishing a dike by giving a score between 1 and 10. The normalized average group scores from the five groups and the average of the five groups are shown in the table below.

**Table 6.7-17: Normalized average group scores**

| | Group 1 *Technical background* | Group 2 *Municipality worker* | Group 3 *Architects* | Group 4 *Interest organisation* | Group 5 *Technical background* | Average |
|---|---|---|---|---|---|---|
| ***Implementation*** | | | | | | |
| Implementation costs | 10% | 12% | 10% | 13% | 18% | **11%** |
| Running and re-investment costs | 11% | 11% | 9% | 13% | 11% | **10%** |
| Technical effort (feasibility of construction) | 8% | 9% | 10% | 11% | 6% | **8%** |
| ***Synergies*** | | | | | | |
| Recreational | 14% | 13% | 14% | 14% | 11% | **13%** |
| Commercial benefits | 15% | 12% | 9% | 10% | 7% | **10%** |
| Tourism | 11% | 9% | 10% | 10% | 6% | **9%** |
| Aesthetic focus | 11% | 12% | 13% | 11% | 12% | **11%** |
| Environmental concerns | 10% | 15% | 14% | 14% | 14% | **12%** |
| Maintaining normal port operation | 10% | 8% | 12% | 5% | 16% | **8%** |

Overall, the combined normalized average group scores for all groups weighted the importance/relevance of the recreational value when constructing a climate adaptation solution as the most important factor with 13%. Environmental concerns (12 %), implementation (11 %) and aesthetic focus (11%) were also perceived as important/relevant criteria. The technical effort (feasibility of construction) and maintain normal port operation (8 %) were perceived as the least important/relevant when constructing a dike (8%).

The results showed different preferences across the five groups regarding the importance/relevance of the criteria when constructing a dike. One striking result was that the weighing from the two technical groups was very different. To point out two specific examples Group 5 weighted the importance/relevance of implementation costs 18 %, which was the highest score given to any criteria, whereas group 1 only weighted the importance/relevance of implementation costs 10%, which was the lowest weighing out of the five groups. The importance/relevance of the commercial benefits was also perceived very differently. Group 1 weighted commercial benefits 15%, which was the criteria weighted the highest, in contrast with 7% given by Group 5.

There are a number of limitations to the chosen approach that are important to highlight. The workshop was limited to one day. Ideally, it would make sense, simply based on the amount of work, to spread it out over two days. Also because a split-up of the criteria weighting, and adaptation solution brainstorm with subsequent rating exercise is a more suitable approach. This is due to the fact that the weighting exercise is more often not done by experts separately, who can come to a consensus through discussions of the criteria. Afterwards, participants would develop adaptation solutions and use the pre-weighted criteria. As such, this would theoretically ensure a more sound data foundation, with potentially less of a variance in the input, than was the case.

**Analysis of the MCA results**

The diagram below shows the net-flux using a triangular distribution of the nine criteria from the five groups. The diagram confirms the observations above. This is specifically evident in the perception of the importance/relevance of commercial benefits, where group 1 (technical background) weigh this high in comparison to the other group 5.

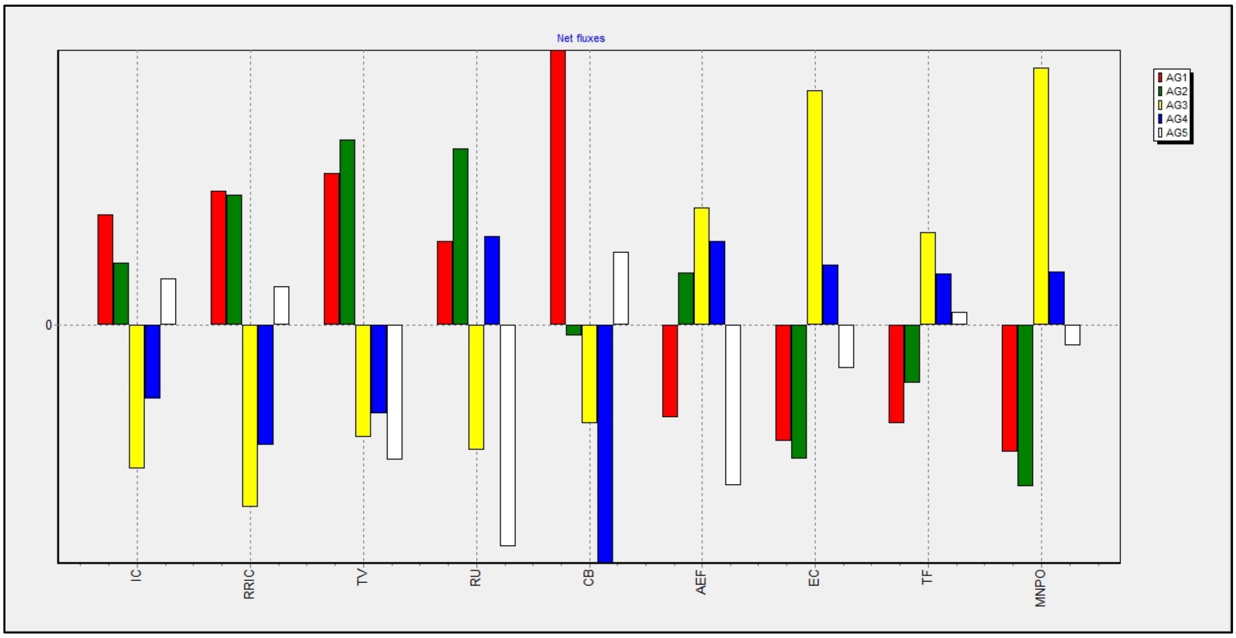



**Figure 6.7-10: Net-flux for the nine criteria using a triangular distribution**

The diagram below shows the net-flux for the nine criteria using an average distribution of the five groups. The results show a similar trend, however there are distinct differences. The net flux values in the average distribution are for instance more pronounced in the implementation costs criteria. The positive net flux values are more positive from Group 1 and 2, and the negative values are more negative from group 3 and 4, compared to the figure above (triangular distribution). The opposite results are shown for the criteria *commercial benefit,* where the positive and negative net flux values are less distinct from the results from the average values.

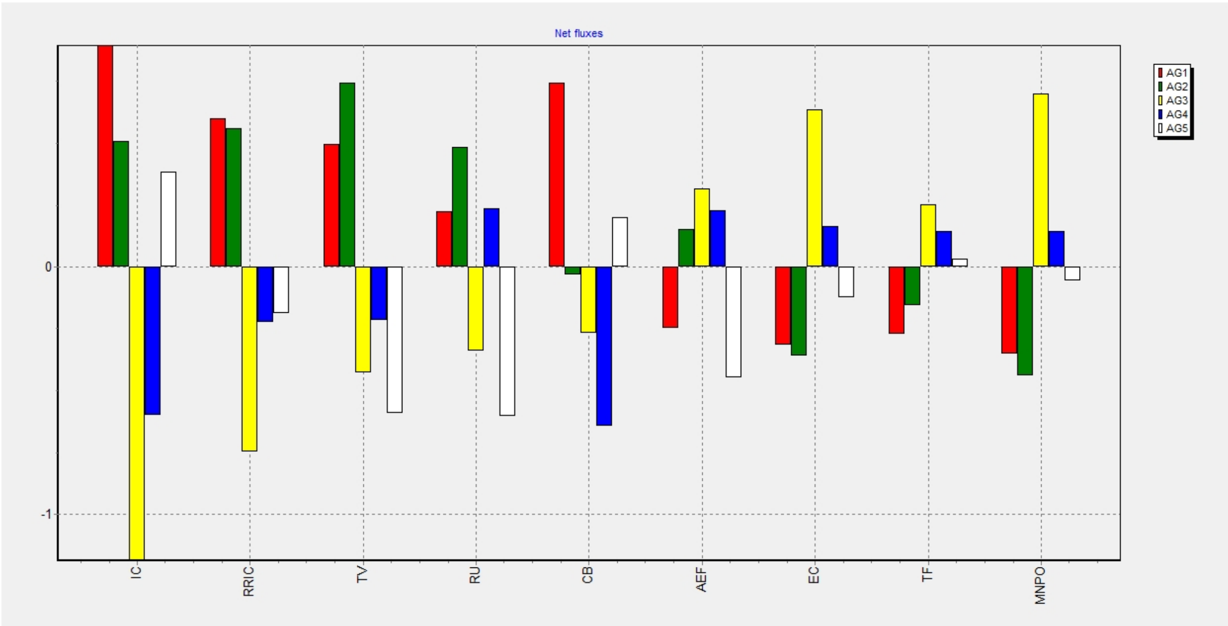



**Figure 6.7-11: Net-flux for the nine criteria using an average distribution**

Overall, it can be concluded that there are large variations in the preferences of the nine criteria. None of the nine criteria stand out being the most relevant/important criteria when constructing a dike because of the variations in the group preferences. For instance the weighing of the criterion *implementation costs* indicated large variations in the group preferences, were high positive flux values were given by Group 1 and 2 and high negative flux values were given by Group 3 and 4.

On the other hand, *aesthetic focus* and *tourism* are two criteria, which were perceived as less important/relevant when constructing a dike.

**Concretization of dike solution**

The dike is supposed to do more than just protect the city from flood surges and the municipality sees an opportunity to create add-ons to the city. To receive input to how the dike can be built the five groups were given time to discuss ideas, challenges, possibilities etc. regarding the dike solution. The five groups proposed a dike solution, which reflected on what function the dike should have besides protecting the city from storm surges. Each group formulated a dike solution that was presented to the participants in plenum. The five dike-solutions where rated from a scale of 1 to 5 for the nine criteria listed below:

a. Implementation costs (planning and completion of climate solutions)

1. Very low implementation costs
2. Low implementation costs
3. Moderate implementation costs
4. High implementation costs
5. Very high implementation costs

b. Running and re-investments costs

1. Very low implementation costs
2. Low implementation costs
3. Moderate implementation costs
4. High implementation costs
5. Very high implementation costs

c. Tourism

1. Very low tourist value
2. Low tourist value
3. Moderate tourist value
4. High tourist value
5. Very high tourist value

d. Recreational

1. Very low recreational use
2. Low recreational use
3. Moderate recreational use
4. High recreational use
5. Very high recreational use

e. Commercial benefits

1. Very few benefits
2. Few benefits
3. Moderate benefits
4. High amount of benefits
5. Very high amount of benefits

f. Aesthetic focus

1. Very low aesthetic focus
2. Low aesthetic focus
3. Moderate aesthetic focus
4. High aesthetic focus
5. Very high aesthetic focus

g. Environmental concern (biodiversity, water quality etc.)

1. Very little environmental concern
2. Little environmental concern
3. Moderate environmental concern
4. High environmental concern
5. Very high environmental concern

h. Technical effect (feasibility of construction)

1. Very difficult to construct
2. Difficult to construct
3. Moderate to construct
4. Simple to construct
5. Very simple to construct

i. Maintaining normal port operation

1. Blocking of port operation
2. Disturbance of port operation
3. Moderate disturbance of port operation
4. Almost no disturbance of port operation
5. No disturbance of port operation

A summary of the dike solutions developed by the five groups is seen below:

**Group 1- Technical background**

Group 1 see the possibilities in taking advantage of the historic defence canal by building a dike as an arch around Copenhagen. There is an opportunity in simultaneously developing Copenhagen's infrastructure by extending the metro-line out to the area where the dike is built. Recreational value is added to the dike by constructing it as a beach park with sand and sports facilities. Group 1 vision a housing development with attractive location on the dike by establishing a neighbourhood with houseboats and canals. It is important for group 1 to maintain the current port operation for shipping, as well as a focus on water quality.

The solution from Group 1 received the highest score on the implementation costs, with an average score of 4.1 points. The criteria environmental concerns received the lowest scores with an average score of 2.81.

**Group 2 – Municipality workers**

Group 2 propose the coastal protection solution to be built as a ring around Copenhagen with a focus on the city's urban. They vision the dike can function as a new urban area with residential and commerce opportunities. The importance of infrastructural improvements is highlighted whereby possible suggestions include metro and/or a road under the ground. It is suggested that the dike can be funded as part of a regional solution, whereby it can be a trademark for the region. An example includes the construction of a reef, which can be seen from the air. Finally, group 2 express the importance of maintaining the current water level.

The solution proposed by the municipality workers received the highest score on the criteria recreation use, with an average score of 4.47, while the commercial benefits received the lowest score with an average score of 2.55 points.

**Group 3 – Architects**

Group 3 associate the harbour of Copenhagen with culture heritage and a big part of the city's identity. The group emphasizes the importance of preserving the historical harbour, whereby it is essential not to screen the medieval city by building a dike. They suggest the dike to be constructed as a recreational island with two locks on each side of the island. These locks are kept open but closed during storm surge situations. The group express the importance of public accessibility to the island.  They also emphasize nature and biodiversity where the effects on Natura 2000 sites need to be examined.

The results from the scoring indicated a high consideration of maintaining normal port operation (average score of 4.1 points), in contrast to commercial benefits, which only received an average score of 1.97 points.

**Group 4 – Interest organizations**

Group 4 express that the harbour is vital for the city and the water quality is important hereby maintaining the water flow is essential. They also sand the port operation is a priority. The group propose that a recreational island with locks will protect the city. Following the establishment of the recreational island it will be investigated how the city will develop and adapt accordingly, by for example investigating the dike's commercial and residential opportunities. Group 4 express a concern regarding the regional component, whereas it is important to find out, how the dike can be a benefit for the entire region. Technically their proposal suggests the dike should be built as an extension of Amager Beach, where the northern part of the island will function as a beach park. They also see the opportunities of the dike connecting traffic, which can service the eastern part of the city.

The presented solution from Group 4 received high scores for recreational use (3.9), environmental concerns (3.96) and maintaining normal port operation (4.0). On the other hand, commercial benefits was the criterion with the lowest score receiving an average score of 2.07.

**Group 5 – Technical background**

The proposal from group 5 suggests the dike to be built as an island, which can function as a part of the city's urban development. They suggest that the sea side will be built in a high elevation functioning as residential housing, whereas the inland side is a recreational area such as a beach. During storm situations the island will act as a protection barrier for the city by taking some of the wave impact. They see the infrastructural opportunities for the dike to connect with the rest of the city by metro. However, group 5 express a commercial obstacle in the existing water treatment plant located close to the proposed dike, which is important to incorporate in the planning of dike.

The other group with a technical background received the highest score on implementation costs with an average score of 3.69 points. The criterion with the lowest score was recreational use (average score of 2.86 points).

**Evaluation and Discussion**

The results from the workshop were run through the decision support tool PRIMATE. For more information on PRIMATE see introduction.

Below is a table with the range (minimum and maximum) and average scores of the five dike solutions alternatives for the nine criteria. The results indicate a large range of scores for all the solutions and criteria, where the score varies from 1 to 5 for many of the criteria.

**Table 6.7-18: Scorecard of solution alternatives**

| Criteria | Group 1 - Technical background | | | Group 2 - Municipality worker | | | Group 3 - Architects | | | Group 4 - Interest organisation | | | Group 5 - Technical background | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Min. | Avg. | Max. | Min. | Avg. | Max. | Min. | Avg. | Max. | Min. | Avg. | Max. | Min. | Avg. | Max. |
| Implementation costs (planning implementation of solutions) | 1 | 4.10 | 5 | 1 | 3.79 | 5 | 1 | 2.43 | 5 | 1 | 2.90 | 5 | 1 | 3.69 | 5 |
| Running and re-investment costs | 2 | 3.53 | 5 | 2 | 3.50 | 5 | 1 | 2.45 | 5 | 1 | 2.87 | 5 | 2 | 2.90 | 5 |
| Tourist value | 2 | 3.77 | 5 | 2 | 3.97 | 5 | 1 | 3.03 | 5 | 1 | 3.20 | 5 | 1 | 2.90 | 5 |
| Recreational use | 2 | 3.86 | 5 | 2 | 4.47 | 5 | 1 | 3.50 | 5 | 2 | 3.90 | 5 | 1 | 2.86 | 5 |
| Commercial benefits | 2 | 3.41 | 5 | 1 | 2.55 | 5 | 1 | 1.97 | 5 | 1 | 2.07 | 4 | 1 | 3.11 | 4 |
| Aesthetic focus | 1 | 3.57 | 5 | 2 | 3.52 | 5 | 2 | 3.93 | 5 | 2 | 3.72 | 5 | 1 | 3.11 | 5 |
| Environmental concerns (biodiversity, water quality) | 1 | 2.81 | 5 | 1 | 2.70 | 5 | 2 | 4.10 | 5 | 1 | 3.96 | 5 | 1 | 3.28 | 5 |
| Technical implementation of the solution | 1 | 2.41 | 5 | 1 | 2.68 | 5 | 1 | 3.66 | 5 | 1 | 3.39 | 5 | 1 | 3.14 | 5 |
| Maintaining normal port operation | 1 | 2.82 | 5 | 1 | 2.61 | 5 | 2 | 4.34 | 5 | 1 | 4.00 | 5 | 1 | 3.52 | 5 |

The large ranges in the scores indicate substantial differences in preferences. The table below expresses the uncertainties in the total net flux of the 5 solution alternatives by using a triangular distribution. The red bars show the mean scores of the 5 solution alternatives compared to the reference point. Solution alternative from Group 1 has highest net flow considering the preferences from all stakeholders involved in the voting, whereas solution alternative from Group 5 has the lowest net flow. The yellow bars indicate a very strong variance around the mean value, indicating a high degree of uncertainty in the results. The high level of uncertainty can be attributed to the value margins used and the varying stakeholder preferences.

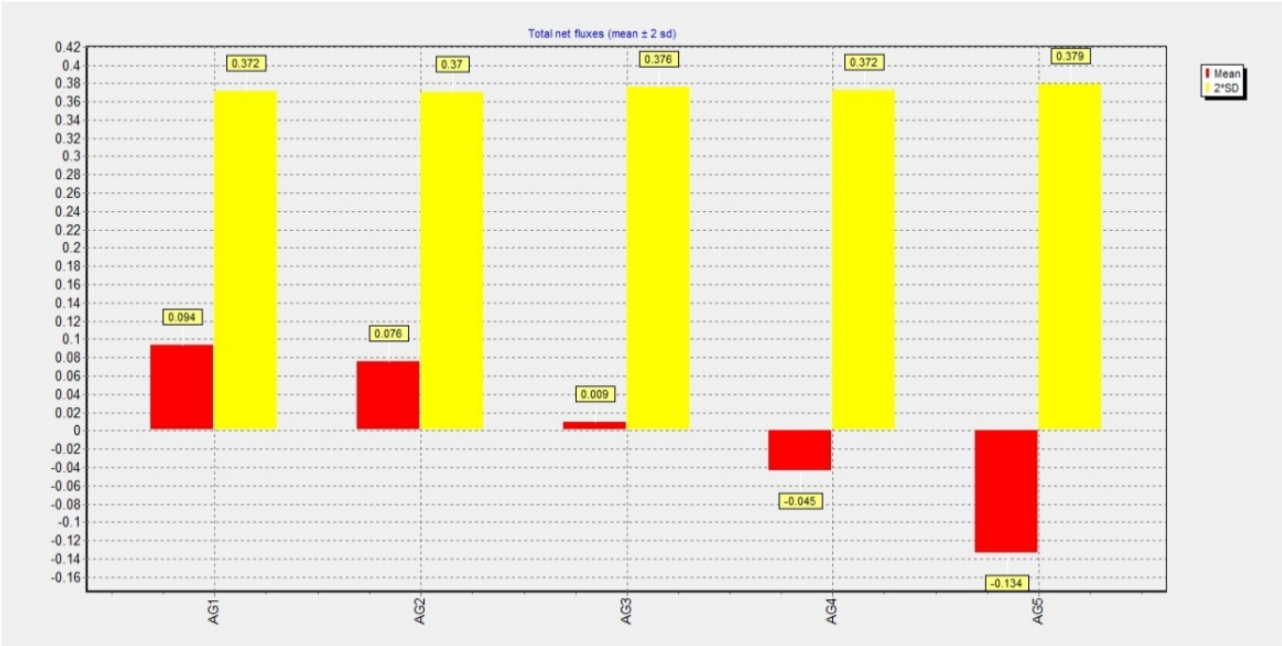



**Figure 6.7-12: Uncertainties in total net flux of the 5 alternatives by triangular distribution**

To eliminate the uncertainty connected with the large range in the scores, an average distribution is used. The figure below illustrates the total net flux uncertainty of the average values. Compared to the total net flux uncertainty, the yellow bars showing the uncertainty connected with the variance of the scoring due to the varying stakeholder preferences are lower. The red bars indicate a more pronounced difference between the performances of the alternatives. The results of the solution alternative from Group 3 indicate a positive mean net flux value in the triangular distribution, but a negative mean net flux value using the average distribution. However overall, the results lead to similar conclusions showing that the dike solution proposal from Group 1 and 2 has the highest net flow considering the preferences from the stakeholders, whereas the solution alternative from Group 5 has the lowest net flow.

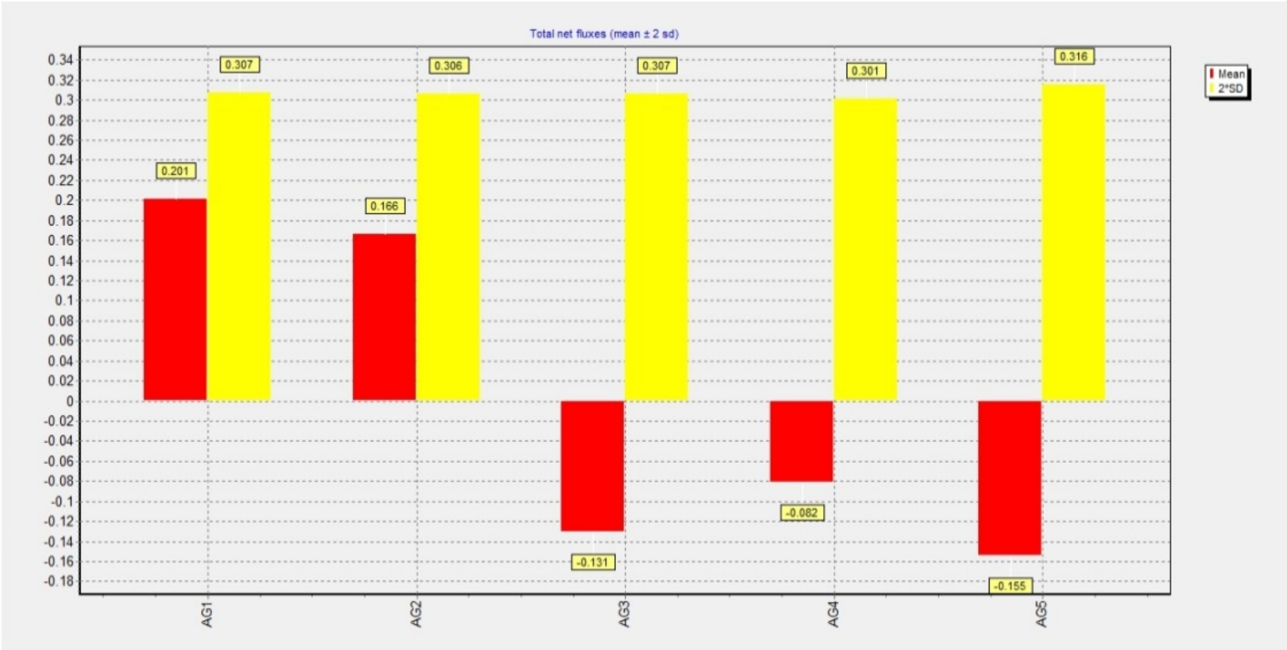



**Figure 6.7-13: Total net flux uncertainty of the average values**

The average distribution is chosen in the further presentation and assessment of the results, in order to eliminate the uncertainty associated with the large range in the scores.

The figure below illustrates the ranking alternatives from the average values, which in other words shows the probability of an alternative to be ranked first. Based on the results there is a 32% chance of the solution alternative from Group 1 will be ranked first. In contrast, there is a 40% probability of solution alternative from Group 5 will be ranked last. On this basis solution from Group 1 is most likely to be ranked first, whereas solution from Group 5 is very probably the least preferred alternative.

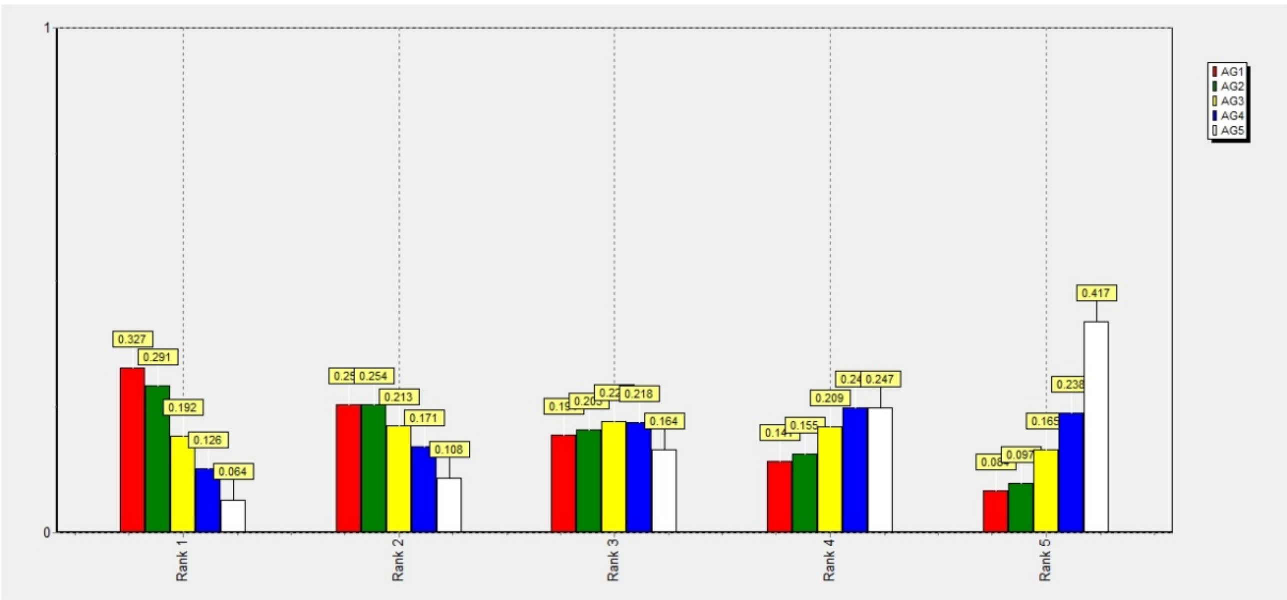



**Figure 6.7-14: Ranking of alternatives based on the average values**

The figure below shows the average net flow preferences of the 5 stakeholder groups. The results show that the net fluxes of all five decision makers was highest for the solution alternative from Group 1 and 2. Whereas the solutions from Group 3, 4 and 5 has the lowest net flux. A large degree of consensus was observed in the decision makers' preferences. The same trend was seen by all the decision maker groups for the 5 solution alternatives, while a slight variation in the net flux value can be seen.

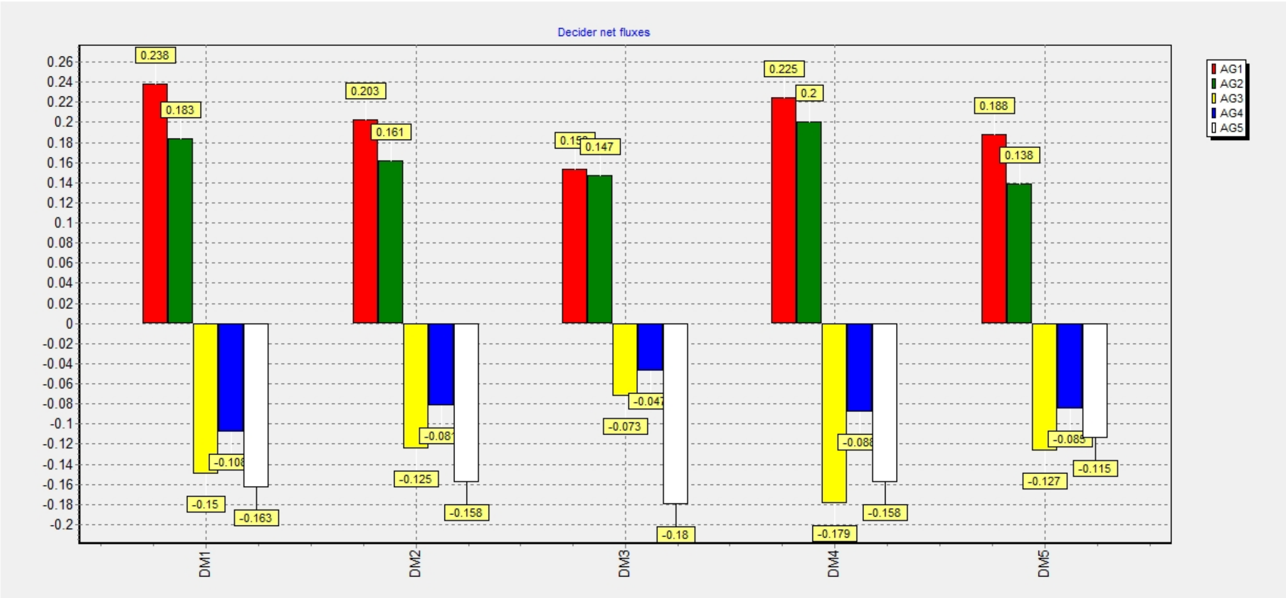



**Figure 6.7-15: Average net fluxes of the 5 stakeholder groups for each alternative**

The figure below shows the net flux average value for the five alternative solutions. From the average distribution it is assumed that the average scores reflect the performance of the alternatives with regards to the respective criteria. The results show that none of the five solution alternatives have solely positive net flux or negative net flux values, which means that there was no solution alternative, which only received high or low scores for all nine criteria. It can thereby be concluded that none of the group solutions managed to incorporate the criteria in their proposed solution alternative. To highlight key results, the solution alternative from Group 1 had a high net flux for the criteria *implementation costs* and *commercial benefits*, but low net flux for *technical effect* and *maintaining normal port operation*. The solution alternative from Group 3 received high net flux for *environmental concerns* and *maintaining normal port operation.*

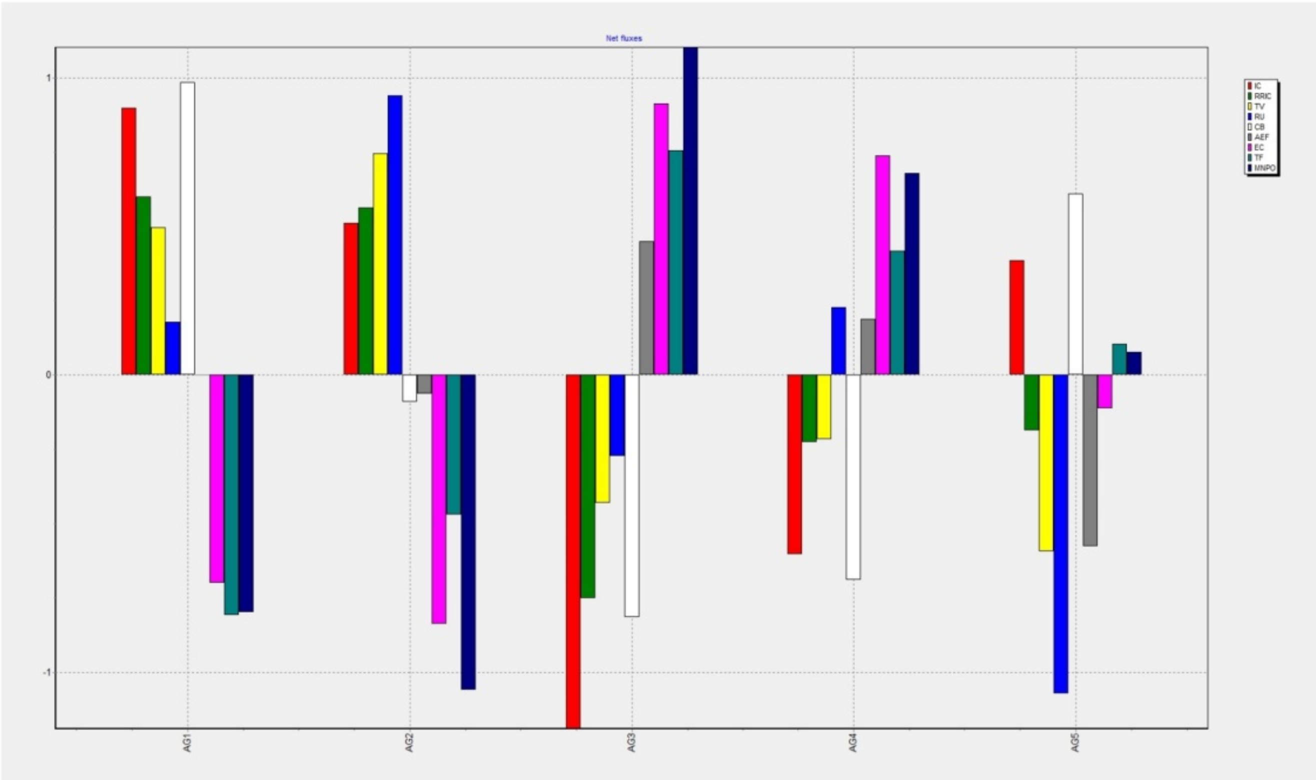



**Figure 6.7-16: Net fluxes for the 5 alternatives by criterion**

Despite the uncertainty involved, it can be concluded that among the 5 alternative solutions the results indicate that there is a strong preference for implementing the alternative from Group 1. It is obvious there are uncertainties in the methodological approach, which reflected the data output. The uncertainty could possibly have been minimized if the workshop was spread out on two days, hereby separating the weighing and scoring of the developed solution alternatives.

## 6.8 Kalajoki river basin – Flood risk management

Anne-Mari Rytkönen, Milla Mäenpää, Noora Veijalainen, Tiia Vento, Mika Marttunen, Antti Parjanne, Finnish Environment Institute - SYKE

**Introduction**

In the economic analysis of the flood risk management measures, we focus on multi-criteria analysis of the measures. In MCA, we evaluated the positive and negative impacts, costs and feasibility of the measures in qualitative and, whenever possible, quantitative terms. In addition, a postal survey (contingent valuation) about citizens' flood perceptions, acceptability of flood risk management measures as well as willingness to pay for improved flood protection level was carried out. The results give additional information of the expected benefits of flood protection. The results of the survey provide a monetary value for gained wellbeing related to flood risk management.

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

**What is the climate change related problem/risk you would like to reduce by adaptation?**

*Which problems already exist, what is/are the current risk/s?*

Due to low lake percentage (1.82%), the Kalajoki river basin is characterized by large intra-seasonal variations in discharge, resulting in frequent floods and low discharge in dry periods. Ditching and dredging projects in the river basin have fastened the runoff. In addition, flood protection measures, mainly embankments, have reduced the natural flood plains. On the other hand, water level regulation in lakes helps to equalize the extreme discharges. The mean discharge in lower part of the river is about 30m$^3$/s. Spring floods caused by snowmelt as well as ice dams floods are frequent in Kalajoki main channel.

*Which assets and sectors are at risk under current climate variability?*

The BASE case study focuses on the Ylivieska-Alavieska region that is nominated as nationally significant flood risk area. Currently there are in total 620 inhabitants and 530 buildings in the area that is inundated in an extreme flood (1/1000a). Most risk sites in the study area are protected by embankments. The embankments are exceeded by a flood with return period 1/50a … 1/100a. The damage caused by a 1/100a return period flood remains under 10 m EUR. When the embankments are exceeded, the estimated damage is multiplied. The damage of 1/250a flood exceeds 15 m EUR and 1/1000a flood 25 m EUR (Table 6.8-1).

There are altogether three public buildings, considered as vulnerable sites in the flood risk area: a hospital, sheltered home and an elementary school. The flood may interrupt public and private traffic routes and besiege buildings. In the flood risk site, there are in total 10 animal farms. During flood, the access to farms may be interrupted.

Flooding increases loading of nutrients and suspended solids to watersheds, especially during summer and autumn floods when the land is unfrozen. Nutrient leaching from the farms may cause environmental impacts. In addition, there are two peat-mining sites in the flood risk area that may cause environmental loading during flood.

**Table 6.8-1: Flood consequences in Alavieska-Ylivieska flood risk area**

| Flood return period | 1/20-yrs. | 1/5-yrs. | 1/100-yrs. | 1/250-yrs. | 1/1000-yrs. |
|---|---|---|---|---|---|
| Damage (m EUR) | 1.72 | 2.91 | 6.55 | 17.27 | 25.31 |
| No. of citizens | 208 | 283 | 370 | 471 | 617 |
| Citizens in the flood protected area | 189 (91 %) | 177 (88 %) | 139 (55 %) | 0 | 0 |
| No. of buildings | 188 | 242 | 316 | 396 | 527 |
| Traffic routes (km) | 0.35 | 0.65 | 3.1 | 10.3 | 12.4 |

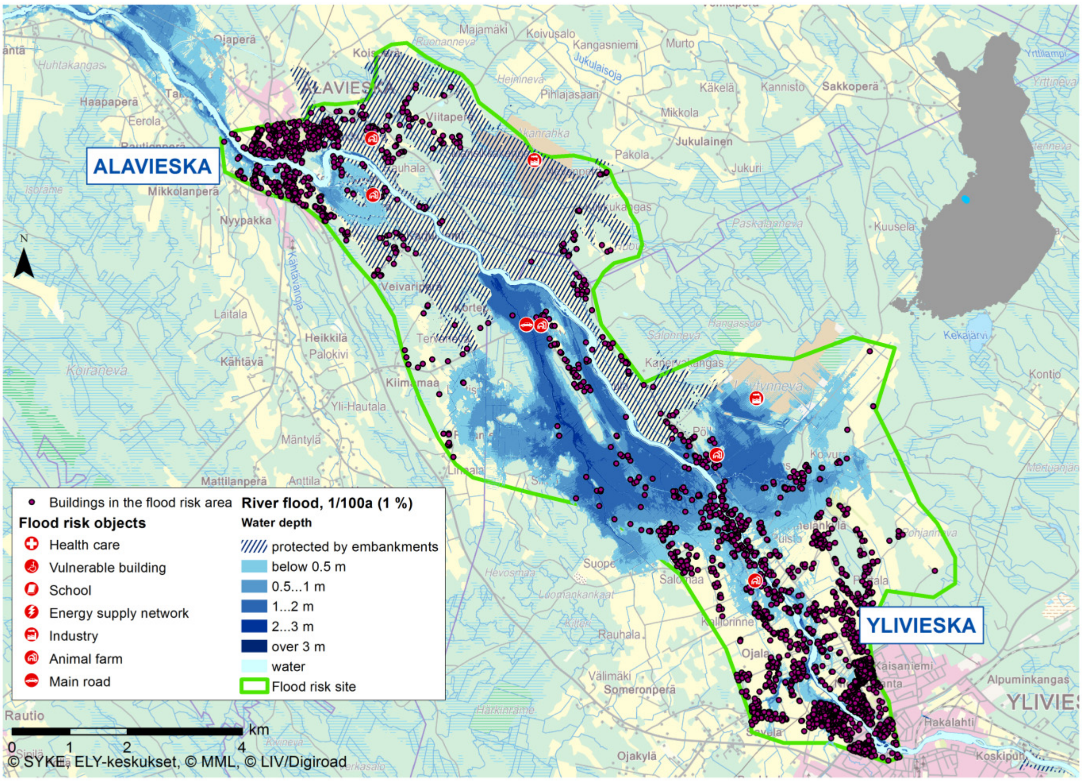



**Figure 6.8-1: Flood risk map Alavieska-Ylivieska, flood return periods 1/100a**

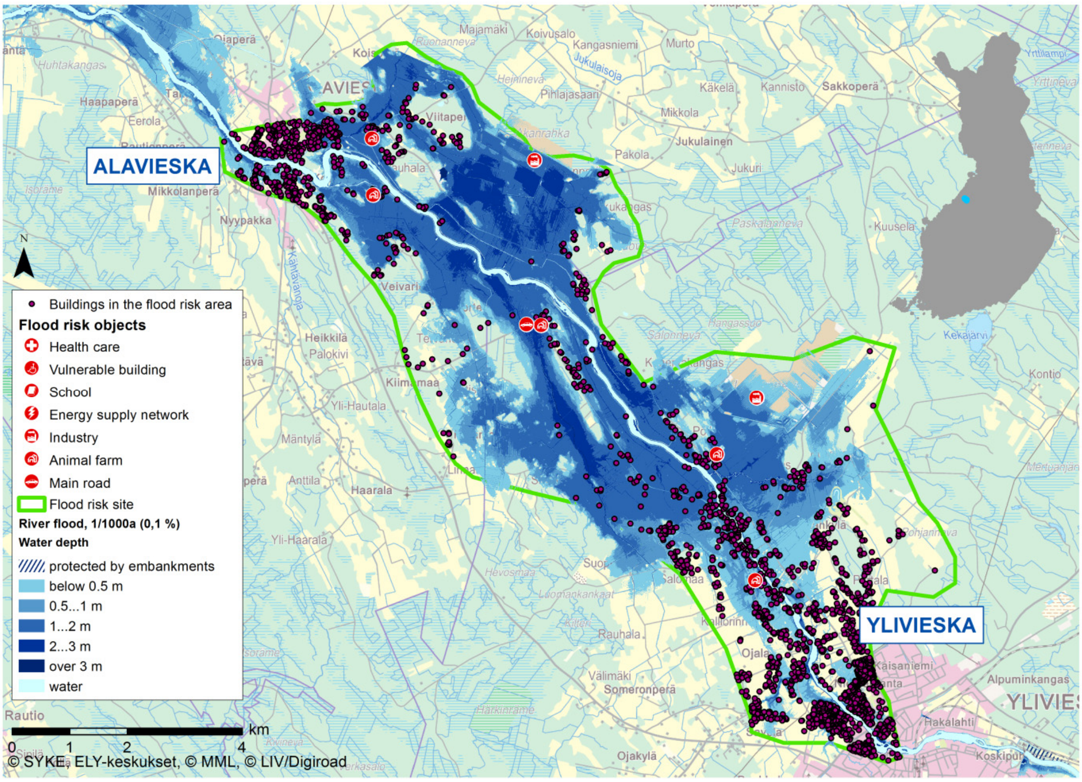



**Figure 6.8-2: Flood risk map Alavieska-Ylivieska, flood return period 1/1000a**

**Which adaptation or protection measures are already in place?**

Non-structural measures:

- Operational flood protection activities
- Land-use planning
- Guidelines for building: lowest building levels, regulations related to bridges and culverts
- Flood modelling, forecasting and warning
- Flood risk mapping
- Evacuation and emergency planning
- Emergency rehearsals
- Preparedness of landowners and citizens
- Flood documentation

Structural measures (floods, human settlements and infrastructure):

- Flood embankments to protect households and cultural sites along the main channel
- Embankments to protect agricultural land (about 70 kms) along the main channel
- Dredging of the river channel and submerged weirs
- Hydropower plants/dams
- Water level regulation of natural lakes
- Water level regulation of artificial reservoirs (5)

**How do these risks presumably change due to climate and socio-economic change?**

In Kalajoki river basin, based on 90 years record period in Niskakoski hydrological observation station, no reliable conclusions can be made on shift of peak discharge to earlier period or change in peak discharge magnitudes. Based on modelling, the flood with 100-year return period is projected to decrease on average 17 % in 2010–2039 and 18 % in 2070–2099. However, differences between different climate scenarios remain large; the range of projected changes was -28–(-7.4) % in 2010–2039 and -32– +1.3 % in 2070–2099. The highest discharges are still predicted to occur in mostly spring, but floods in other seasons are expected to become more common. The higher winter discharges may increase risk for frazil ice dams (Veijalainen et al. 2009).

The population is expected to decrease in Kalajoki river basin. On the other hand, pressure may increase for more intensive land use on low-lying waterfront areas.

**What are the main drivers, impacts and affected sectors?**

The case is mainly developed and implemented because of other policy objectives, but with consideration on climate change adaptation aspects. The main driver in flood risk management planning is legislation: the national implementation of the Floods Directive. The Alavieska-Ylivieska region in Kalajoki river basin was nominated as a nationally significant flood risk site, based on the likelihood of flooding and the major negative consequences of extreme floods. For those river basins having one or more flood risk sites a flood risk management plan will be published by the end of 2015. When assessing the flood risks and preparing the flood risk management plans, the historical floods as well as the anticipated changes in hydrology and climate are taken into account.

Referring to the categorization of BASE case studies, main impacts in the Kalajoki case are river flooding and shift of season. Affected sectors include human settlements and infrastructure, human health, biodiversity and ecosystems, agriculture and water management.

**Which climate and socio-economic scenarios are used?**

The climate change predictions presented in chapter 1D have been produced using WSFS hydrological model (Vehviläinen et al. 2005), the delta change method and 20 different climate scenarios from both global and regional climate models using three SRES-emission scenarios (Veijalainen et al. 2010).

New simulations have recently also been carried out with both new scenarios and new methods, but these results are yet to be published. They include simulations with delta change method using new climate scenarios from the IPCC 5$^{th}$ assessment report. These use also the new RCP scenarios for emission and greenhouse gas concentrations. The total number of IPCC 5$^{th}$ assessment report scenarios is 124, although some have unrealistic changes in temperature and have therefore been excluded as outliers.

New scenarios have also been carried out using bias corrected direct regional climate model data as input to the hydrological model (Veijalainen 2012). Bias correction has been implemented by the Finnish Meteorological Institute using Distribution Based Scaling method (Yang et al. 2010). These new scenarios produce mostly similar results than the previous results, with, for most part, decreasing flood risks in the future.

Figure 6.8-1 and Figure 6.8-2 in this document present simulated discharges at Niskakoski observation station in the reference period and in future time periods with bias corrected direct daily data from HadRM-HadCM3-A1B scenario and HIRHAM-ARPEGE-A1B scenario.

**Which adaptation tipping points can be identified?**

The objectives for flood risk management, set by the flood management group, can be used as tipping points. The first tipping point has been reached already in the current status, as all the objectives set by the flood management group are not met. However, as the flood peaks are predicted to decrease in the future, no further tipping points can be seen to emerge based on magnitude of the floods.

Other type of tipping points may emerge based on increased seasonal variation in hydrological conditions. This has major impacts on water level regulation, as current practices and objectives may become unpractical or not effective in flood mitigation. In the lake area in Finland, it has been assessed that current regulation practices may function mainly during 2010–203, but changes need to be made by 2040–2039 (Jakkila ym.)

**Table 6.8-2: Objectives and tipping point-traffic lights – water level regulation**

| Objectives for water level regulation | When tipping points will be reached (due to cc) | Critical levels / triggers | Alternative measures |
|---|---|---|---|
| Water level license and target water levels are obeyed<br>Winter: to create storage capacity for spring flood<br>June-August: high water level for recreational use | Near future, <10 years<br>Pressure: smaller spring floods;<br>Water level decrease during winter become unnecessary in most years,<br>Good summer water levels may not be reached due to smaller runoff | Regulation limits cannot be obeyed or are unreasonable to obey at least every tenth year<br>Too low spring/summer water levels cause significant harm to recreational use at least every fifth year | To have more flexibility in water level licenses instead of water levels being fixed to calendar dates |
| Reservoir storage capacity is efficiently used to cut the flood peaks | Near future, < 10 years<br>Pressure: autumn and winter floods increase and become more common due to increased precipitation and because snow melts more often during the winter | The situations where there are late autumn and winter floods cause damage occurs at least every tenth year | To keep water levels in lakes permanently 20-40 cm lower in autumn. |

**Table 6.8-3: Objectives and tipping point-traffic lights – flood risk management**

| FRM objective | When tipping points will be reached (due to cc) |
|---|---|
| The flood peaks (the extreme water levels and discharges) do not grow despite climate change | **Not likely**<br>Based on the climate scenarios the flood peaks do not grow but the seasonal variation of floods will change. |
| Living and working in population centres is secured up to 1/100a floods | **Reached already**<br>370 citizens and 125 residential buildings in 1/100a flood risk area. |
| All new residential/leisure buildings are secured up to 1/100a flood | **Not likely**<br>if risk levels taken into account in land use planning |
| Vulnerable buildings are protected up to 1/250a flood | **Reached already**<br>1 school building is at risk |
| The flood embankments in population centres are secure up to 1/100a floods. The other embankments are secure up to 1/50a floods | **Reached already**<br>In total, 190 citizens in the area protected by embankments, 50 of those are not safe in 1/100a flood.* |
| The function of telephone and data networks is secured up to 1/100a floods. No prolonged interruption in water and energy supply in 1/100a floods | **Not likely**<br>Flood does not affect the electricity supply centres. |
| The major roads are usable up to 1/100a floods | **Reached already**<br>3,1 km interrupted roads |
| No vital economic activities are located in the flood risk area | **Not likely** |
| The ecological status of water bodies will not decline due to floods or flood risk management measures | **Reached already**<br>10 animal farms and peat extraction sites in the flood risk site may cause loading during floods. |
| No incompensable damage to cultural heritage. New libraries, archives and museums are protected up to 1/250a floods. | **Not likely** |
| Industrial or agricultural buildings are usable up to 1/50a flood. New buildings are protected up to 1/250a floods. | **Reached already**<br>25 animal shelters or other agricultural buildings are located in 1/50a flood risk area. |

Note: * The embankments protect only a part of the flood risk area.

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

**What are the alternative adaptation measures?**

The selection of measures was carried out in three-step analysis. In a preliminary assessment, flood risk management measures were grouped in three categories. The first category included feasible, "obvious" measures that did not require further analysis. These included e.g. improving flood communication to citizens as well as current flood management measures. In the second category included measures that would need further analysis. They were:

1. Using agricultural land as floodplains
2. Extended use of regulated lakes as water storage
3. Improving summer flood preparedness in Hautaperä reservoir regulation
4. Improving summer flood preparedness in lake Reisjärvi regulation
5. Increasing the retention capacity of the river basin
6. Permanent flood protection structures

The third category included measures that were not feasible or applicable in the case study area. This group included mainly large-scale "grey" measures, such as

- Relocation of buildings and activities
- Building a new reservoir
- Bypass channels
- Dredging of the river channel

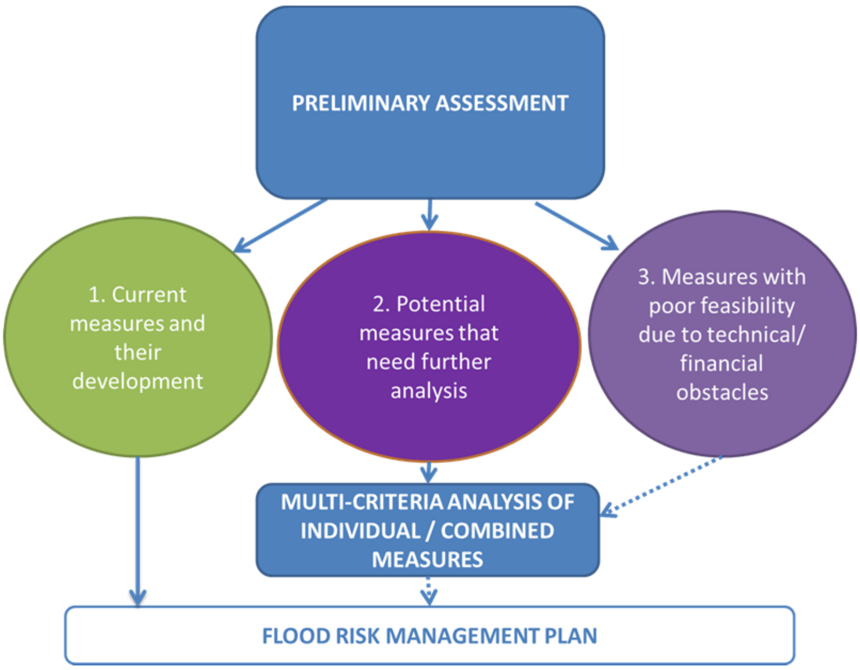



**Figure 6.8-3: Scheme for selecting the measures in Kalajoki river basin**

**What are the primary and secondary objectives of adaptation?**

The main objectives are to reduce flood risk, mitigate negative flood consequences and promote preparedness for floods. The more specific objectives, set by the Kalajoki flood management group, were presented in Table 6.8-4.

**What are potential measures to meet these objectives?**

**Table 6.8-4: Potential measures in Kalajoki case study**

| Characteristic | Generic measure | Example measure | Potential in Kalajoki Case study (Y/N) |
|---|---|---|---|
| **Non-structural** (applicable to all impacts and sectors) | Awareness raising | Campaigns, stakeholder meetings, education | Y |
| | Disaster response management | Evacuation plans, early warning systems, water rationing schemes, | Y |
| | Economic incentives | Subsidies, taxes, shares, water pricing, nature farming, building codes | N |
| | Risk transfer tools | Insurance, catastrophe bonds | Y |
| | Monitoring and management | Information and communication systems, screening, forest management, permits for (ground)water use, | Y |
| | Land use planning | Risk zoning, nature conservation areas, connecting nature areas, crop rotation | Y |
| **Structural** Floods, Human Settlements and infrastructure, Coastal protection | Improving flood defences (engineering) | Dikes, dams, barriers, flood walls, artificial reefs | Y (maintenance of existing) |
| | Improving flood defences (building with nature) | Coastal sand nourishment, wetlands, | Y (not as main alternative but as a supplementary measure) |
| | Giving Space to rivers | Widening, deepening, side channels, green rivers, removing obstacles | N |
| | Improving drainage | Increasing capacity, decoupling, permeable pavement, WADI's | N |
| | Improving water retention (peak flows) | Upstream basins, emergency retention areas | Y (regulated lakes) |
| | Flood proof building and design | Wet- and dry proof building, save shelters, floating houses | N |
| **Structural** Water, Resources management, Agriculture, Droughts | Water conservation | Basins, aquifer storage and recovery | N |
| | Water saving measures | Drop irrigation, House hold water saving measures | N |
| | Ground water management | Water level control, | N |
| | Water technology | Recycling of water, desalinization | N |
| **Structural** Health, Human settlements and infrastructure | Measures to minimise exposure to diseases | Vector control (vector habitat destruction, bed nets and repellents). Food sanitation and hygiene (refrigeration, chlorination of drinking water, etc.). Water and sanitation systems. Planning of city parks and controlled burning of vegetation. | N |
| | Heat proof building and design | Green roofs, water in the city, wind lanes. Thermal buildings insulation, use of fans coolers and air conditioning. Green spaces, trees in streets and open places, increased ventilation between buildings. | N |
| | Flood and heat resilient infrastructure | Engineering solutions such as flood protection structures (e.g. dams, dykes, walls and raised banks, pump stations), river channelization, bridges. Reforestation, soil protection, restoration of riparian zones. Flood-resistant buildings. | N |

**What is your baseline option?**

The baseline is to keep up the current flood protection standards and risk levels → no additional measures taken into account in the baseline. The current flood management measures include flood communication and self-directed preparedness of citizens, flood insurance (since the beginning of 2014), operational flood management measures and water level regulation (including ice dam prevention) and maintenance of flood embankments.

*What is the ambition level of this baseline strategy? Maintaining current risk levels or current protection levels?*

In the baseline strategy, no additional measures are implemented.

*Is current backlog of investments for adaptation measures included or excluded?*

Excluded, as the current objectives are not met. The baseline is the current protection level excluding the investments to fulfil the objectives.

*Does it include only planned adaptation or also autonomous, non-planned adaptation?*

Mainly planned adaptation.

Are there complementary measures? Is it appropriate to bundle these measures?

Complementary measures are above all flood risk mapping as well weather and flood forecasting is the latter is a trigger to start implementing most operational flood risk management measures. As these complementary measures belong mainly to category 1 (current measures and their development), it was not seen necessary to include these measures in the multi-criteria assessment. In addition, evaluation of each measure individually was seen to increase the transparency of the assessment.

As there was no single, feasible measure that would solve the problem alone, combination of measures will be needed to achieve the objectives.

**What are alternative adaptation pathways?**

As the flood peaks are predicted to decrease in the future, no further tipping points can be seen to emerge based on magnitude of the floods. Instead, tipping points may emerge based on increased seasonal variation in hydrological conditions. The current water level regulation practices and objectives may become unpractical or not effective in flood mitigation. In springtime, low water levels for spring flood become unnecessary and on the contrary, storage capacity is not sufficient for autumn floods. In the lake area in Finland, it has been assessed that current regulation practices may function mainly during 2010–2030, but changes need to be made by 2040–2039 (Jakkila ym.). Alternative measures in these tipping points would be a) to have more flexibility in water level licenses instead of water levels being fixed to calendar dates, and b) to keep water levels in lakes permanently 20-40 cm lower in autumn.

**Step 3 - Evaluation Criteria and Method**

**Step 3a Selection of evaluation criteria**

**Which evaluation criteria should be used?**

The evaluation criteria used are presented in Figure 6.8-4. They include the flood protection benefits in floods of three different return periods in the flood risk site and elsewhere in the river basin; ecological, social and economic side effects of implementation; technical, juridical and political feasibility; potential risks or uncertainties related to the anticipated impacts or implementation as well as implementation costs. The evaluation criteria were selected by experts and accepted by stakeholders in a workshop.

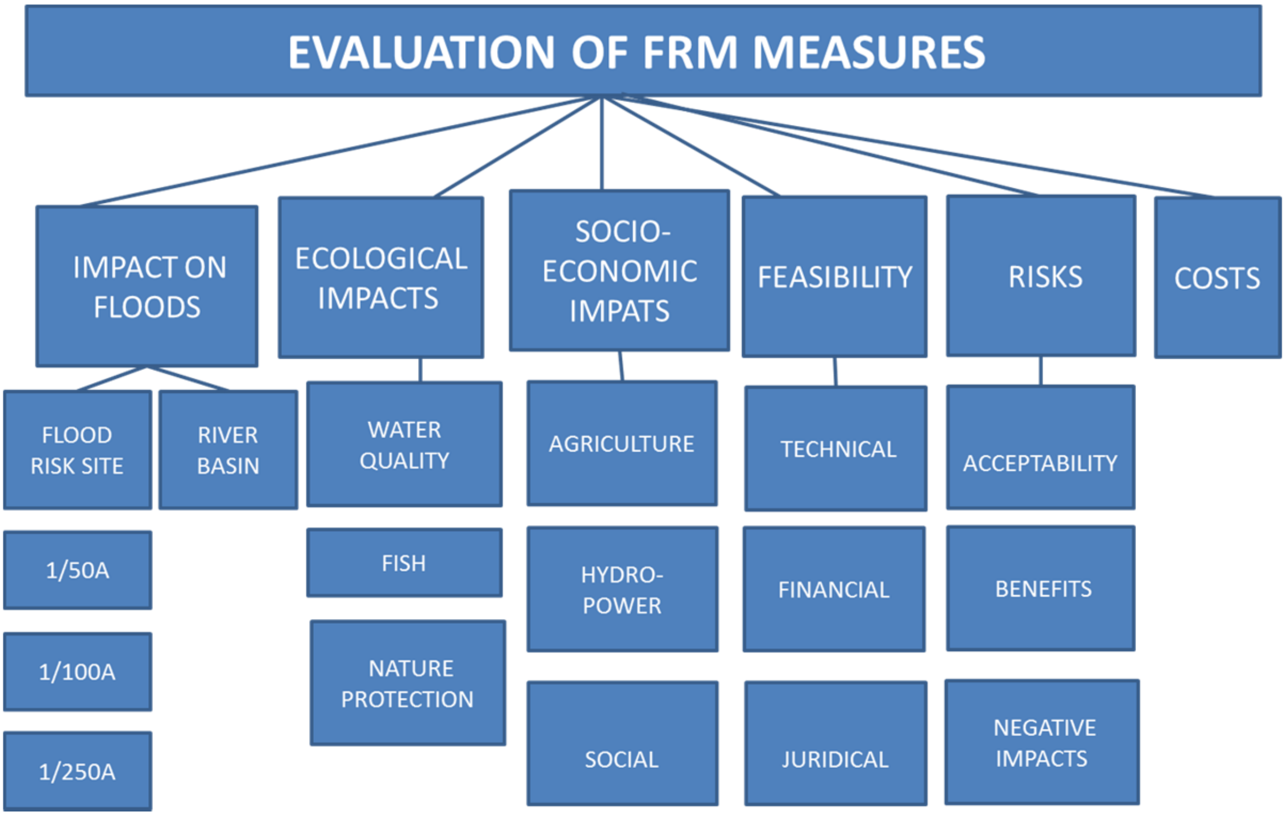



**Figure 6.8-4: The evaluation criteria for the flood risk management measures**

**What is the appropriate unit to measure each of these criteria? Is the performance of the adaptation options measured in qualitative, monetary or other quantitative terms?**

The performance of measures was measured in semi-quantitative terms using the assessment scales presented in the following tables.

**Table 6.8-5: Impact on floods**

| | |
|---|---|
| No impact: 0 | No impact |
| Small: 1 | Small positive impact: reduces damage < 10 % or reduces discharge or water level < 10 % of what is needed to avoid damage. Not sufficient alone. |
| Medium: 4 | Medium positive impact: reduces damage about 40 % or reduces discharge or water level about 40 % of what is needed to avoid damage. Not sufficient alone. |
| Large: 7 | Large positive impact: reduces damage about  50–70 % or reduces discharge or water level about 50–70 % % of what is needed to avoid damage. Not sufficient alone. |
| Very large10 | Large positive impact: reduces damage about  80–100 % or reduces discharge or water level to the level that damage can be avoided with current flood protection measures |

**Table 6.8-6: Ecological and socio-economic impacts**

| Scale | Examples |
|---|---|
| Large – – – | Large, wide-ranging, long-term or permanent negative impact |
| Medium – – | Medium, long term negative impact on small area or temporary impact on large area. |
| Small – | Small, temporary and local negative impact |
| No impact | No impact |
| Small + | Small positive impact |
| Medium + + | Medium positive impact on large area or large positive impact on a small area. |
| Large + + + | Large, wide-ranging positive impact. |

**Table 6.8-7: Feasibility**

| | Technical | Juridical | Financial |
|---|---|---|---|
| Good | Former experience, no problems expected | No problems expected related to permissions | Realizer known, financing ok |
| Moderate | Only little experience, some challenges | Some challenges in permit process | Uncertainty related to realizer / financing |
| Poor | A demanding measure, no former experience | Large uncertainties related to permissions. | Uncertainty related to both realiser and financing |

**Table 6.8-8: Risks**

| | Political | Benefits | Negative impacts |
|---|---|---|---|
| Small | Small risk for conflicts | Small/no uncertainty related to expected benefits | The negative impacts can be foreseen reliably |
| Moderate | Moderate risk for conflicts | Moderate risk related to realization of benefits | The negative impacts can be foreseen quite reliably |
| High | Large risk for conflicts | High risk related to realization of benefits, e.g. timing of water storing, behaviour of citizens etc. | The measure may have negative impacts that are difficult to foresee. |

**Step 3b Selection of evaluation method(s)**

**What is the appropriate evaluation method?**

All flood protection benefits cannot be measures in monetary terms for several reasons. Firstly, there are large uncertainties related to the damage estimations. The damage curves are done centrally and cover the whole country, thus they may contain errors that have not been inspected. For example, the building heights are not known in GIS-registers. In addition, design of the measures was done in a very general level in flood management groups, meaning their investment, maintenance and administrative costs have been inadequately estimated. For these reasons, a full-scale CBA could not be done and would not even be reasonable in strategic flood risk management planning. In this phase, the measures were assessed in a multi-criteria matrix using the assessment scales presented in the tables above.

It should also be noted that many flood risk management measures in Finland are multi-objective measures. For example, water level regulation aims for flood mitigation, hydropower production and producing recreational benefits. In addition, different public and private actors might implement measures. This makes it difficult to compare the cost-effectiveness of the measure only from flood protection point of view. Basically, structural flood protection measures, above all flood embankments, are the only measures where it makes sense to compare the avoided damages with the costs.

**Step 3c Weighting of evaluation criteria**

**What are the preferences of stakeholders regarding the different evaluation criteria?**

In the MCA method used in SYKE, criteria weighting is usually based on swing-method. However, weighting of the criteria was not applied in the Kalajoki case even after the impact assessment. There were several reasons for that:

- Based on the hydrological modelling, it turned out that the benefits of the measures were smaller than expected. Thus, the range of effective measures narrowed down and no alternative strategies could be created.
- There were no measures that would exclude each other. A variety of measures would be needed to meet the objectives. The key question in the decision-making was rather to prioritize the potential measures and to discuss the acceptability and responsibilities related to those.

The criteria weights are always context-specific and cannot be transferred from one case to another. Just to give an example, in the flood risk management project in Ivalojoki, point allocation weighting was used. There, on average 57 % of the overall weight was allocated to flood protection benefits, 21 % to socio-economic side-effects and 21 % to ecological impacts (Kurkela 2014).

**Step 4 - Data collection**

**What are the costs and what are the benefits of the alternative adaptation options?**

SYKE together with ministries for the Environment and for Agriculture and Forestry started a project in 2010 aiming at developing assessment methods for benefits of flood risk and river basin management. In a report by Lehtoranta et al. (2011), potential evaluation frameworks and methods were assessed.

When it comes to flood risk management, the benefits are primarily presented as avoided costs compared with the current flood protection standards. The potential beneficiaries include citizens, businesses and service users in the floor risk area. The wider society can also benefit from protecting the environment or cultural heritage. The assessment should cover direct and indirect, as well as material and immaterial flood consequences. In addition to avoided damages, other benefits can be biodiversity, hydropower and recreational use (e.g. peatland restoration and development of water level regulation). (Lehtoranta et al 2011).

In the flood risk management planning in Finland, the benefit assessment is mainly based on pricing approaches instead of valuation approaches. The benefits of measures or their combinations are defined roughly based on the views of experts and stakeholders (MCDA), as other than monetary benefits (social, ecological and cultural benefits) are difficult to evaluate. (Lehtoranta et al 2011).

Silander & Parjanne (2012) have developed an excel-based method for coherent assessment of monetary flood risk in all flood-risk-mapped regions in Finland. The flood maps have been prepared for return periods 1/20a, 1/50a, 1/100a, 1/250a and 1/1000a in total 103 areas in Finland. The flood maps cover mainly river or lake floods and some sea level rise floods. The return period is defined statistically based on river discharge or lake water level.

The damage functions are based on flood maps and spatial databases. A national Building and Dwelling Register contains detailed attribute data of buildings (type, area, no. of floors etc.). The functions present anticipated monetary damage for different types of buildings as a function of water depth (depth-damage functions). The water depth classes used are 0–0,5 m; 0,5–1,0 m; 1–2 m; 2–3 m and over 3 m. As a presumption, flood protected areas are excluded.

The method takes into account the following assets:

- Buildings
  - Structural (price per m$^2$ for different building types)
  - Moveables
  - Cleaning
- Traffic
  - Road and railroad infrastructure
  - Change in traffic routes (additional time for using detour)
- Rescue service costs during floods
- Vehicle damages
- Number of people (no monetary values, only number)

**Table 6.8-9: Flood damage estimation in the lower course of the Kalajoki river basin**

| **Flood frequency** | **5 %** **1/20a** | **2 %** **1/50a** | **1 %** **1/100a** | **0,4 %** **1/250a** | **0,1 %** **1/1000a** |
|---|---|---|---|---|---|
| **Total damage (m EUR)** | | | | | |
| **Buildings** | **1,72** | **2,91** | **6,55** | **17,27** | **25,31** |
| Structural | 0,99 | 1,70 | 3,96 | 10,76 | 15,77 |
| Cleaning | 0,08 | 0,20 | 0,44 | 1,45 | 2,08 |
| Chattel | 0,65 | 1,02 | 2,15 | 5,06 | 7,46 |
| **Traffic** | **0,13** | **0,23** | **0,71** | **1,70** | **2,21** |
| additional time | 0,01 | 0,01 | 0,03 | 0,07 | 0,10 |
| traffic infrastructure | 0,12 | 0,21 | 0,68 | 1,63 | 2,11 |
| **Evacuation** | **0,11** | **0,19** | **0,43** | **1,13** | **1,66** |
| **Vehicles** | **0,02** | **0,03** | **0,09** | **0,29** | **0,44** |
| **Total** | **1,98** | **3,36** | **7,78** | **20,40** | **29,62** |

Smaller than 1/20a floods and flood damages have not been modelled for the case study region. If we assume smaller floods do not cause any damages, the expected annual damages would be 80,000 EUR (floods from 1/20a to 1/1,000 a taken into account). Based on the flood damage observations, this seems to be too optimistic. If we assume that 1/5a flood would cause damage of 100,000 EUR and 1/10a flood damage of 500,000 EUR, the expected annual damage would rise up to 490,000 €. If our objective is to protect the infrastructure and buildings by embankments up to 1/100a flood the expected annual benefit would be 300,000 EUR. The residual risk for an extreme flood event (likelihood less than 1 % per year) would then be 190,000 EUR/a.

It should be noted that that the common, small floods have a large impact in expected annual damages. Due to uncertainties related to national GIS-registers, small errors in data (e.g. a couple of buildings wrong in a data) may lead to big errors in damage estimates when stretched to a 100 year time period. Therefore it would be essential to check the risk objects and damage estimates locally before using them.

A corresponding method could be developed to evaluate loss of business opportunities and services, losses for water and energy supply and losses for agriculture and forestry. In a GIS-register for agricultural land, the areas of field plots and cultivars are available. A challenge in estimating agricultural/forestry damages is that they are highly dependent on the duration and season of flood incident. Cultural heritage and critical infrastructure are not taken into account in available damage estimations. (Silander & Parjanne 2012).

As the climate changes, the damage in certain water depth does not change, only the likelihood of the event. Agriculture is an exception, as the yields are expected to increase, or more valuable crops can be used due to warming climate, which may increase agricultural damage caused by floods.

The method can be used to evaluate the benefits of structural flood protection measures by comparing the current water levels to the water levels achieved by the measure. As for non-structural measures, estimating the benefits is more difficult, as the investment and maintenance costs are harder to evaluate and the measure proposals are often defined in broader terms or require further specification. According to the national recommendations, assessing the costs and benefits in flood risk management plans can be done in a general level, by explaining which factors are accounted and how they have affected prioritization of management measures. In principle, the net present value of the measures presented in FRMPs should be positive. But in addition, feasibility of the measures (including legislation, resources and technical requirements), lifespan, and accordance with river basin planning, and adaptive capacity are recommended to take into account in prioritization. Of the costs, investment and maintenance costs are recommended to be included (Parjanne 2014).

In addition to flood damage estimations, also other data sources are available. The government paid compensations for flood damages until 2013. The statistics do not cover all damages, as e.g. moveable property was not covered from the government budget. In addition, stormwater and sea level rise floods were not included. The insurance companies have statistics on the realized flood damage from the few recent years. In the database of the Ministry for Agriculture and Forestry, there are data of applied and granted agricultural damages since 1995 (garden, tree stand, crops, other) by property.

In the questionnaire for the citizens of Kalajoki and three other river basins done within the BASE project, the willingness to pay for flood protection was studied. The questionnaire gives an indication of the value of “increased water safety” – e.g. how the local citizens perceive the flood risk, how much they have/are ready to invest on flood management measures or how many would be ready to extend their home insurance to cover flood damages.

Based on the questionnaire, an average annual willingness to pay for private flood protection measures was 34.7 EUR per household during 6 years period on average. In the Ylivieska-Alavieska flood risk zone (about 1 500 households), this would mean about 52,000 EUR annual benefits for increased water safety. Only small number (8 %) of respondents had already implemented flood protection measures but the sums used were significant (from hundreds to tens of thousands of EUR). 22 % of the respondents could consider implementing flood protection measures in the future and 17 % could consider extending their home insurance to include flood damage compensation.

**Impacts on floods**: Experts or consultants responsible for flood risk management planning. Potential data sources: literature, experiences from realized projects.

**Ecological impacts**: experts responsible for river basin planning, fisheries management and management of Natura 2000 sites. Potential data sources: literature, experiences from realized projects.

**Socio-economic impacts**: Experts responsible for flood risk management planning, city planners, hydropower companies, stakeholders, experiences from realized projects.

**Feasibility**: Experts responsible for flood risk management planning, experts on environmental law, former projects.

**Risks and costs**: Experts responsible for flood risk management planning

Based on hydrological simulations, a few main conclusions can be drawn on water retention and water level regulation as flood risk management measure.  Firstly, if the storage basins are located far upstream from the flood risk area, it may not be effective in flood mitigation an extreme flood, even when their theoretical capacity is large. Hydrological processes are complicated e.g. due to the delays created by the soil moisture storage and the retention created by multiple lakes. Secondly, a seemingly large increase in the retention capacity in forested areas and wetlands did not have an impact in an extreme flood. Without regulation dams etc., the storage capacity of these is used already in the beginning of the flood, and the flood peaks cannot be cut when needed the most.

Use of agricultural land seemed a promising flood control measure, but the studied floodplain turned out to be too small to offer enough storage space. Due to the low profile of the land, a floodplain area with sufficient storage capacity would be very large in area and its implementation costs: draining the floodplain by pumping, potential damage to agriculture and infrastructure, such as erosion in the floodplain area, would probably exceed the flood protection benefits.

**Table 6.8-10: Evaluation of the selected measures in a multi-criteria matrix**

| | Impact on floods | | | | Ecological | | | Socio-economic | | | | Feasibility | | | RISKS/ UNCERTAINTIES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1/50a Flood risk site | 1/100a Flood risk site | 1/250a Flood risk site | Elsewhere in the river basin | Water quality | Biodiversity | Fish | Agriculture | Hydropower | Fishing and recreation | landscape | Technical | Financial | Juridical | Acceptability | Benefits | Negative impacts | **Costs (m EUR)** | **Implementation time (years)** |
| Use of agricultural land as floodplains | 4 | 1 | 0 | + | + | 0 | 0 | + | + | 0 | 0 | Mod | Mod | Mod | Mod? | Mod? | Mod | Over 5 | 6-12 |
| Extended use of regulated lakes as water storage | 1 | 0 | 0 | - | 0/+ | 0 | 0 | - | + | 0 | 0 | Mod | Mod/ poor | Poor | Mod | Mod | Mod | several m | Over 6 |
| Improving summer flood preparedness in hautaperä reservoir regulation | 1 | 0 | 0 | - | - | -- | -- | - | + | -- | - | Mod | Mod/ poor | Mod | Mod/ small | Mod | Mod | hydrop. losses | 0-6 |
| Increasing the retention capacity of the river basin (small scale measures) | 1-0 | 0 | 0 | + | ++ | + | + | + | 0/+ | + | + | Good | Good | Good | Small | Small | Small | | Over 6 |
| Increasing the retention capacity of the river basin (large scale; drained lakes, post-peat production sites into wetlands) | 1-2 | 0-1 | 0 | + | + | + | + | -- | + | + | + | Mod/ poor | Hu | Mod | Mod | Mod | Mod | over 1 | Over 6 |
| Permanent flood protection structures | 10 | 10 | 10/0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -- | Good | Mod | Mod | Mod/ small | Small | Small | 200 EUR/m | Public: 0–6 Private: over 6 |

**What is the evaluation time frame?**

According to the national recommendations (Parjanne 2014), the recommended lifespan in cost-benefit analysis should be 50 years. For some long lasting measures also time horizon of 100 years could be used.

**Which discount rate should be applied?**

According to the national recommendations for FRM planning and EU guidelines (Parjanne 2014), the discount rate should be 3,5 %, sensitivity analysis is recommended to do with 5 %.

In very expensive measures with a long lifespan, a discount rate declining in time is recommended: first 50a 3,5 %, 50-70a 3 % and 75-100a 2,5 %.

**How to deal with data uncertainty?**

In multi-criteria analysis, min-max ranges can be used for certain measures (e.g. private homeowners' preparedness).

For cost-benefit analysis, it is recommended to use a sensitivity analysis (Parjanne 2014). It is recommended to find out critical figures, when the investment is feasible or when the ranking order of the alternatives changes, e.g. by calculating the internal interest rate.

The method for evaluating the flood damages (Silander & Parjanne 2013) includes a number of national defaults, some of which can be changed for sensitivity analysis, for example anticipated duration of the flood, average building heights, proportion of chattel value of the building value, average length of detour and the price for temporary accommodation per night.

**Step 5 – Evaluation and Prioritization**

**What is the ranking order of alternative adaptation options (measures, bundles of measures or pathways)?**

The flood management group did not base their decision making on economic analysis due to reasons explained in step 3b: uncertainties and insufficient data on costs and benefits. We did a simple "cost-benefit analysis exercise" to see whether the measures seemed to be feasible or not from flood protection perspective.

For some measures, the exact amount of structures needed was not stated in the flood risk management plan draft, so we made some assumptions based on other documents:

- Wetlands in agriculture: the objective is to establish 105 new wetlands in the river basin district for 2016-2020. The agricultural land of the Kalajoki river basin (69,455 ha) is about 20,5 % of the whole RBD → number of wetlands 21. Average size of a wetland is 1,22 ha.
- Water retention in forested areas: there are about 1966 ha of forestry area in need of renewal of ditch drainage in Kalajoki river basin, which is about 9,4 % of the provincial area. When compared with the river basin management plan objectives, 100 new water retention structures such as wetlands or controlled drainage would be needed.

We evaluated, whether the measure were feasible or not. The bigger the internal interest rate means better feasibility. We also calculated, if and when the measure would pay itself back. Based on this exercise, building flood embankments is the most feasible measure. In addition, the measures related to water level regulation seem feasible due to their small investment/maintenance costs, even though they bring only small benefits. Using floodplains and increasing water retention seem not feasible in the light of the current data.

**Table 6.8-11: Exercise on costs and benefits of flood risk management measures**

| Measure | Amount | Annual benefit | Investment cost | Maintenance cost (annual) | Feasibility |
|---|---|---|---|---|---|
| **Water retention (small scale) in agriculture and forestry** | 21 wetlands * 1,22 ha = 25,6 ha<br><br>100 new water retention structures | Total: max. 10 % of 1/50ª flood: 20,000 EUR | Wetlands: 11,500 EUR/ha → 295,000 EUR<br><br>Forestry: 100 * 2,900EUR = 290,000 EUR | 18,300 EUR<br><br>11,500 EUR | Not feasible as flood control measures with any discount rate. Would not pay itself back. |
| **Building embankments** | Estimated need 20 km | If fully implemented: 100 % of 1/100ª flood: 300,000 EUR | 200 EUR/m + planning 100 000 EUR → 4,7 m EUR | 5,000 EUR/year (inspection) | Feasible measure. Internal interest rate 6 %. Payback time 23,7 years. |
| **Floodplains** | Total volume 5,75 $m^3$ | Max 40 % of a 1/50ª flood: 80,000 EUR | 2 m EUR | 48,000 EUR Potential agricultural damage | Not feasible as flood control measure. Would not pay it back. |
| **Lake regulation (+ 0,5 m)** | three lakes | Total: max. 10 % of 1/50ª flood: 20,000 EUR | Planning 200,000 EUR, no structures needed | 10,000 EUR Administrative costs Potential agricultural damage not estimated | Potentially feasible measure. Internal interest rate 4 %. Payback time 35 years. |
| **CC adaptation in lake regulation** | | Total: max. 10 % of 1/50ª flood: 20,000 EUR | Planning 250,000 EUR, no new structures needed | 10,000 EUR Administrative costs Hydropower losses not estimated | Potentially feasible measure. Internal interest rate 3 %. Payback time 60 years. |

Note: Interest rate 3,5 % and timeframe 50 years were used. The costs of measures are based on national figures. For wetlands, the investment costs is based on agro-environmental subsidy (CAP).

As mentioned earlier, no MCA model was run in the Kalajoki case, mainly because no alternative measures/bundles of measures could be found. Therefore there were no trade-offs to be made where mathematical MCDA model would have been helpful.

In the 2nd stakeholder workshop, the results of the impact assessment were presented and discussed. The participants were asked to prioritize the measures in a questionnaire form based on the impact matrix and their own perspective. Both current and new potential measures were included. The results are presented in Figure 6.8-5.

Of the current measures, flood communication and citizen's preparedness were prioritized the highest. Of the new measures, permanent flood protection structures and using agricultural land were considered the most important.

Compared with the prioritization of measures by citizens from the postal survey, the citizens highlighted maintaining the current embankments (62 %), water level regulation (51 %) and building new flood protection structures (42 %) as the most important flood management measures. Only 20 % of the respondents mentioned residents' flood awareness and property owners' preparations as primary measures (Figure 6.8-6).

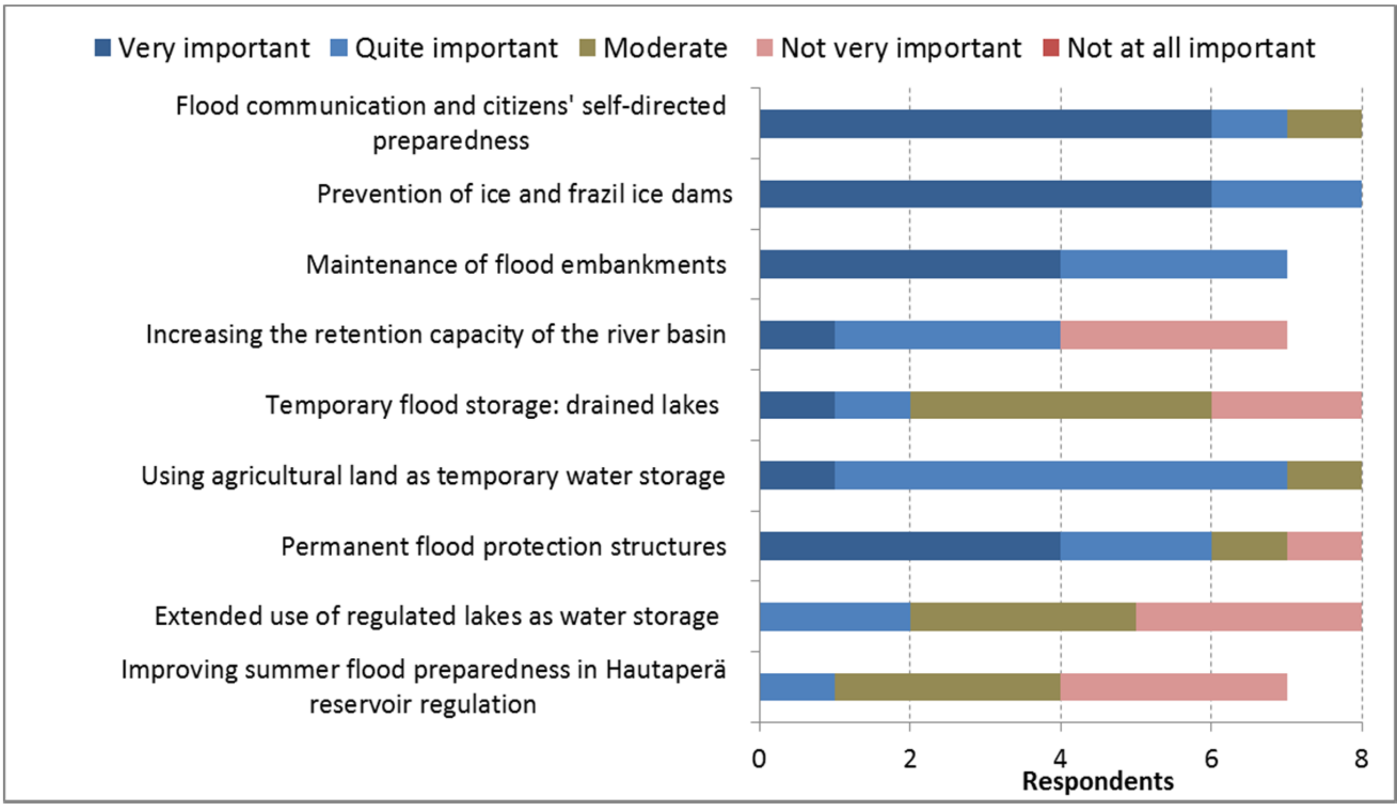



**Figure 6.8-5: Preferences on the measures of the participants in the second workshop**

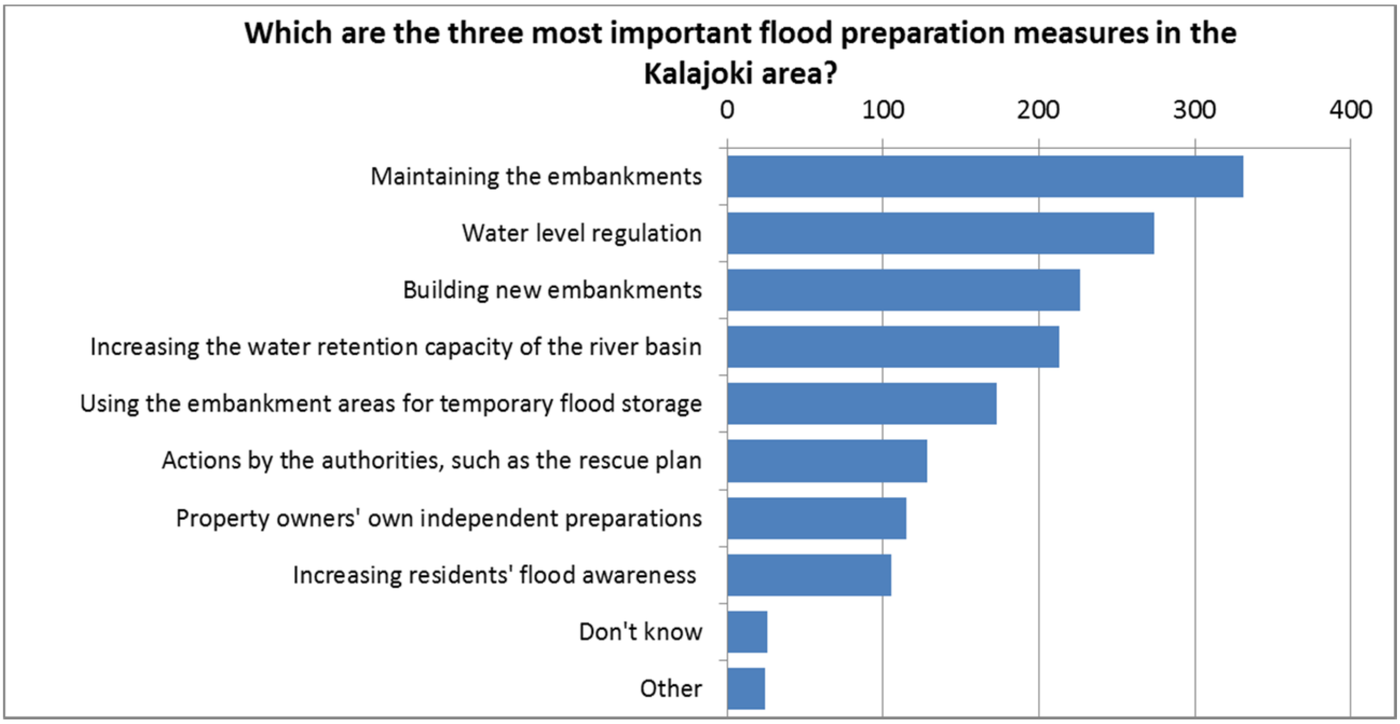



**Figure 6.8-6: Prioritization of measures from citizen questionnaire (n=549).**

The decision on the selection of measures in the flood risk management plan draft was done by the flood management group (Table 6.8-12). In this prioritization, mainly current and non-structural measures were given priority no 1. This included adapting lake regulation practices to climate change. New flood embankments were given the second priority, as the final decision would require more detailed mapping and cost-benefit analysis. The same applies to using agricultural land as floodplains. As the flood risk management plan is a general level document, detailed planning of individual measures was not in the scope of this work.

**Table 6.8-12: Prioritization of measures, as set in the flood risk management plan draft**

| Measure | Prioritization | Suggestion |
|---|---|---|
| Flood risk mitigation and preparedness – current measures | Primary | E.g. avoiding building in the flood risk zone, flood modelling, forecasting and warning, cooperation among officials, citizens' awareness and preparedness |
| Operational flood risk management – current measures | Primary | E.g. Developing water level regulation to adapt to climate change, ice dam prevention |
| Maintenance of existing flood embankments | Primary | Periodic inspection and clarification of responsibilities |
| Increasing water retention capacity of the river basin | Primary | Taking retention capacity into account all land use. Favouring water protection measures that increase retention capacity (e.g. wetlands) |
| New permanent flood protection structures | Secondary | Mapping the potential areas, study on feasibility, costs and benefits of implementation |
| Flood documentation with help of citizens | Complementary | Development of an open web-service for uploading photos and other flood documentation data |
| Using agricultural land as floodplains | Complementary | Specification of the measure, study on technical feasibility, costs and benefits |
| Recovery | Primary | Reconstruction, cleaning, measures to promote physical and mental wellbeing of citizens. |

**What are the uncertainties associated with the performance of the different options?**

The uncertainties related to assessing the benefits of measures were presented in Table 6.8-11. The greatest uncertainty is related to measures whose benefits depend on the actions done just before or during the flood peak. These are especially the measures related to water level regulation.

Converting the agricultural land to part-time floodplains would require building of the floodgates and some new embankments. The realization of benefits is greatly dependent on whether the storage capacity is used at the optimal moment cut the flood peak. For the optimal timing of the opening the floodgates, the weather forecasts should be able to predict the flood peak accurately. In addition, if the measure would be in use very seldom, there's a risk for human mistakes. The same uncertainty applies to water level regulation in lakes.

The most reliable flood risk management measures are those based on solid structures such as embankments. They don't require any specific actions during the flood. Small uncertainty of course is related to break of an embankment, but this risk can be minimized by adopting a regular inspection practice in as set in the dam safety act. At the moment, the act applies mainly to regulation dams and not flood embankments.

It is also very difficult to assess to what extent flood communication and guidance would influence citizens' and property owners' preparedness and eventually reduce flood damages.

As there were not major conflicts related to ranking of the alternatives and the solution was found by negotiation, no significant uncertainties are related to the ranking itself. However, insufficient data related to some measures, e.g. need and final costs of new embankments, as well as feasibility of floodplains, may change the priorities when further studies are conducted. In the actual implementation, funding and responsibilities are the most crucial issues to cause uncertainty.

For the uncertainties related to multi-criteria analysis in flood risk management projects in general, see next section (lessons learned).

Building of the permanent flood embankments performs best as it is an only reliable measure to avoid flood damages in an extreme 1/100a flood. However, to gain better understanding of the costs and benefits, further information is needed both of building new flood embankments as well as using floodplains. The measures based on water retention or regulation turned to be too uncertain or their capacity insufficient in an extreme flood. However, for climate change adaptation, small changes to water level regulation seem feasible, as they do not need big investments, only tuning of current practices.

## What are the main lessons learnt from your case study?

**Transferability of the results**

Kalajoki is typical river of the Ostrobothnia in the west coast of Finland. The catchments in this area are relatively small, have a small lake percentage and as a consequence, limited retention and regulation capacity. The area is sparsely populated, but with several small municipalities located near the rivers it is still one of the vulnerable regions for flooding in Finland.

Also the climate change impacts are similar in many river basins in the west coast of Finland. In areas currently dominated by snowmelt floods, a decrease in flood discharges and flood hazard is expected by 2070–2099 due to decrease in snow accumulation. Autumn and winter floods increase and become more common in the future. According to most scenarios, the magnitude of these floods would be smaller than the current spring floods, which implies a decrease in the total flood risk in Kalajoki river basin. In few scenarios, floods may increase in the near future due to increase in precipitation and then decrease by the end of the century. However, increased uncertainty may cause more challenges in the future, as rainfall floods are more difficult to forecast than spring floods.

In many lakes in Finland, adaptation to climate change will require changes and more flexibility in regulation permits. There are mainly two drivers for adjusting the current practices: 1) to reach the optimal water levels for recreational use in summertime and 2) to increase flood storage capacity in the case of autumn/winter flood. Currently, flood mitigation by water level regulation is mainly focused on spring floods, as the water levels are lowered to a minimum to prepare for snowmelt runoff. This may lead to unacceptably low water levels during the summer in years when the snowpack is small. In many lakes the most crucial summertime water levels can be reached during the period 2010–39, but not anymore during the period 2040–39 (Jakkila et al. 2012). In Kalajoki case, the regulation permits are currently under evaluation.

Hydrological simulations show that models are essential tools in assessing the benefits of those measures based on water retention and regulation. In addition, water level regulation is very dependent on weather forecasts. As the climate change proceeds, the importance of forecasts as well as decisions of organizations in charge of water level regulation will increase.

Another key conclusion from the case study analysis is that in dominantly rural areas where the population density is rather low and the financial flood damages are moderate, often the most cost-efficient measure to protect existing infrastructure is to build embankments or use other permanent flood protection structures. Their advantage is also that they function in different conditions and their benefits are not dependent on the success of the weather forecasts. In addition, the most cost-effective measure to minimize future flood risk is land use planning and adoption of the lowest allowed building heights.

**Economic evaluation methods and their feasibility**

Based on the case study experiences, some common conclusions can be drawn from using economic evaluation methods in flood risk management planning context.

In our case, the decision-making in the flood management group was not based on economic analysis. The flood risk management plan is a general, strategic document. In the plan, it was evaluated how the current flood management practices could be developed, which are potential new measures and which deserve to be studied in more detail. Based on the flood risk management plan only, no decisions on new big investments are made.

Multi-criteria methods can bring systematic action and transparency to evaluation of measures. They help to make sure the measures are evaluated against the same criteria using the same metrics. This was found useful in Kalajoki case – even though mathematical multi-criteria model was not used. Multi-criteria modelling tools may be helpful in cases where there are distinct alternatives, a need for making trade-offs and conflicting views among stakeholders.

Even though some extent of uncertainty can be accepted in economic evaluation methods, the result is only as good as the data behind the models. Our case study revealed that it is of a key importance to have a realistic assessment of the benefits of the measures, otherwise the results are not reliable. In this case, evaluation of the potential benefits by hydrological model helped to rule out alternatives that did not fulfil the objectives.

Flood risk management measures in Finland are implemented by several different actors. Traditionally, the state has had a strong role in flood management and still may finance or part-finance some projects of a key importance. The newly introduced act on compensation of flood damages has shifted the responsibility from state to private insurance companies and increased private citizens' responsibility. In addition, also municipalities and businesses are responsible for some measures. Economic analysis is one, and often important issue in decision-making, but there are a number of other issues, political, social or based on legislation, that have an impact on decision-making.

A weakness in economic evaluation methods is that they tend to simplify the complex planning context. Flood risk management itself is a complex issue having multiple objectives. In our case the study area was geographically large and the measures were located in different parts of the river basin, meaning that the benefits and negative impacts would occur in different areas. The climate change impacts brought another element into the assessment, as there is no trend that would gradually intensify. Rather, the total peak floods seem to decrease, but their seasonal variation changes and uncertainty increases. As a consequence, some current measures may turn impractical, and small adjustments are needed instead of new big investments. Sometimes it may be difficult to describe these phenomena with one or two criteria only – or, the criteria should be more carefully selected. Like in our MCA, we evaluated the measures against the extreme floods. As there were not many measures that would fulfil the objectives, most measures seemed useless.

It should also be noted that many flood risk management measures in Finland are multi-objective measures. For example, water level regulation aims for flood mitigation, hydropower production and producing recreational benefits. In addition, measures may be implemented by different public and private actors. This makes it difficult to compare the cost-effectiveness of the measure only from flood protection point of view. Basically, structural flood protection measures, above all flood embankments, are the only measures where it makes sense to compare the avoided damages with the costs.

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## 6.9 Kalajoki river basin – Water quality management

Turo Hjerppe, Milla Mäenpää, Anne-Mari Rytkönen, Tiia Vento, Inese Huttunen, Markus Huttunen, Finnish Environment Institute - SYKE


### Introduction

In the economic analysis of river basin management, we focus on cost-effectiveness of measures to reduce nutrient loading from agriculture and the effectiveness of measures under different climate and agricultural scenarios.

- Preliminary cost-effectiveness analysis for water protection measures: In agriculture, buffer zones and many years of grass cultivation (60–70 EUR/reduced P kilo) when the slope of fields > 6 %. These not feasible in large part of the river basin. Most feasible measure is wetlands.
- Modelling of nutrient loading under different agro-economical (positive and negative change of price and yield of crops) scenarios in current climate and with climate change (4 scenarios)
- Cost-effectiveness analysis of agricultural measures under the studied scenarios: what are the most cost-effective measures under different conditions, how do the results change, why?

The study demonstrates an integrated method of assessing the effect of climate change on agricultural sector, nutrient loading of fields, natural background loading and hydrology. By combining agricultural sector-level model (DREMFIA) with hydrological and nutrient loading modelling (VEMALA), we showed how the agricultural adaptation, together with climate-induced changes in soil processes and nutrient leaching, affect nitrogen and phosphorus transport to the inland water bodies and into the Baltic sea. For assessing the cost-effectives of agro-environmental measures and how it change in future we used a spread sheet tool KUTOVA.

### Nutrient loading model VEMALA

VEMALA is an operational, national scale, nutrient (phosphorus and nitrogen) loading model for Finnish watersheds. It simulates runoff processes, nutrient processes, leaching and transport on land, in rivers and in lakes (Huttunen et al., submitted). The VEMALA model provides an estimate of external loading, outflow loading, retention of nutrients in all ca. 58.000 lakes in Finland, as well as nutrient loading source apportionment into main sources - agriculture, forests, scattered settlements and point sources. The present version of the model consists of a catchment scale, semi-process-based model of total nitrogen (TN) loading, VEMALA-N, and a field scale process-based model for total phosphorus (TP) loading, VEMALA-ICECREAM (Huttunen et al., submitted).

ICECREAM is based on the CREAMS (Knisel 1980) and GLEAMS (Knisel 1993) models, and developed for Finnish conditions by Rekolainen and Posch (1993). Since then, several studies have been published describing its further development and applications (e.g. Tattari et al. 2001, Yli-Halla et al. 2005, Bärlund et al. 2009, Jaakkola et al. 2012, Huttunen et al. submitted). ICECREAM calculates the hydrology of each field plot based on the so-called bucket model. Surface runoff is calculated with the SCS curve number method (Soil Conservation Service 1972) and macropore flow for clay soils with the method developed by Jaakkola et al. (2012). The phosphorus simulation is based on the flow between three mineral P pools and three organic P pools. Particulate and dissolved phosphorus are lost via surface runoff and macropore flow, and dissolved phosphorus also via the water percolating through the soil profile. Erosion is calculated with the modified USLE model (Foster et al. 1977).

Total nitrogen loading is simulated by the VEMALA-N model (Huttunen et al., submitted), which is a catchment scale N leaching model with six land uses defined: spring cereals, winter cereals, grassland, root crops, green fallow and forest. In the VEMALA-N model, nitrate ($NO_3^-$) and organic nitrogen are described separately. Organic nitrogen is modelled using a concentration-discharge relationship in which subsurface and base flow are characterized by different organic nitrogen concentrations. Nitrate is simulated using a semi-process-based model similar to the INCA approach (Wade et al. 2002, Rankinen et al. 2004). $NH_4^+$ storage in the soil is modelled and linked to the soil organic nitrogen and nitrate. The processes included to simulate nitrate leaching are mineralization, nitrification, denitrification, immobilization, plant uptake, fertilizer input, dissolution and nitrogen leaching.

The data used as input include: (1) meteorological data (daily air temperature and precipitation, Finnish Meteorological Institute), (2) hydrological data (daily discharge and water levels, Finnish Environment Institute), (3) water quality monitoring data (Finnish Environment Institute), (4) agricultural field data for all fields in Finland (soil texture, slope, crop from a private soil analysis service company Viljavuuspalvelu Oy), (5) annual point loads from the Compliance Monitoring Data System (VAHTI), (6) number of scattered dwellings from building and dwelling register of Finland.

**Economic agricultural sector model DREMFIA**

Changes in regional level agriculture throughout Finland under these scenarios are evaluated using an economic agricultural sector model DREMFIA. The model simulates production and foreign trade of agricultural commodities, as well as land use (areas under crops and set aside) and production intensity (fertilization, land use) annually from 1995 up to 2020 and produces a steady state static equilibrium for 2030, 2040 and 2050. The model assumes rational economic behaviour and competitive markets, replicates realized production and land use 1995-2012, and produces realistic development paths of agriculture (see Lehtonen 2001 and 2013 for details).

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

**What is the climate change related problem/risk you would like to reduce by adaptation?**

The main problem is that most of the water bodies are in less than good ecological status due to high nutrient loading from agriculture. It is assumed that increased nutrient load from the fields is the most apparent risk to river ecosystem and status. Also, water quantity can vary (minimum flow). In this case study we concentrate on climate change and its effects to ecological status of waters. Already the flooding causes exceeding nutrient loads to water bodies in the case area.

We concentrated in agricultural sector, especially cultivation, which is most likely to be the most affected by climate change and other changes in future.

Agriculture has not taken into account the climate change adaptation or other future scenarios in a systematic way. At national level there are strategies, which are not implemented in local level. Hydrology is one of the main factors, which determines the changes in nutrient loading in future climate.

**Which climate and socio-economic scenarios are used?**

Main classification of BASE storylines is based on shared socio-economic pathways (SSP) in combination with Representative Concentration Pathways (RCP). Summarizing, the storylines defined for BASE are using the following scenarios:

Storyline 1: SSP5 and RCP 8.5 “Market driven development”

Storyline 2: SSP2 and RCP 4.5 “Middle of the road”

Storyline 3: SSP3 and RCP 8.5 “Fragmentation”

Kalajoki case study was oriented to study the climate change effect on agricultural adaptation and nutrient loading. Agricultural change depends on combination of RCP (or SRES scenarios) and world-price scenarios. Therefore Kalajoki case study scenarios are not fully comparable with general BASE storylines, but instead all 3 Kalajoki case agricultural adaptation scenarios lay closest to the Storyline 2: SSP2 and RCP 4.5. The main criteria placing our scenarios in Storyline 2 is climate change scenario RCP 4.5 (closest to SRES A1B), which is moderate climate change scenario. RCP 4.5 is favourable for agricultural development, because of longer growing season, but not so pronounced droughts yet. In contrast, in RCP 8.5 (SRES A2) scenario the crop yield increase might not be so high due to the negative impacts of temperature increase (early summer droughts and longer dry spells during the growing season) (Rötter et al., 2012). The future research would be to develop agricultural adaptation scenarios for Storyline 1 “Market driven development”, and investigated the potential yield increase and nutrient loading in successful, moderate and little adaptation scenarios under RCP 8.5 SSP5.

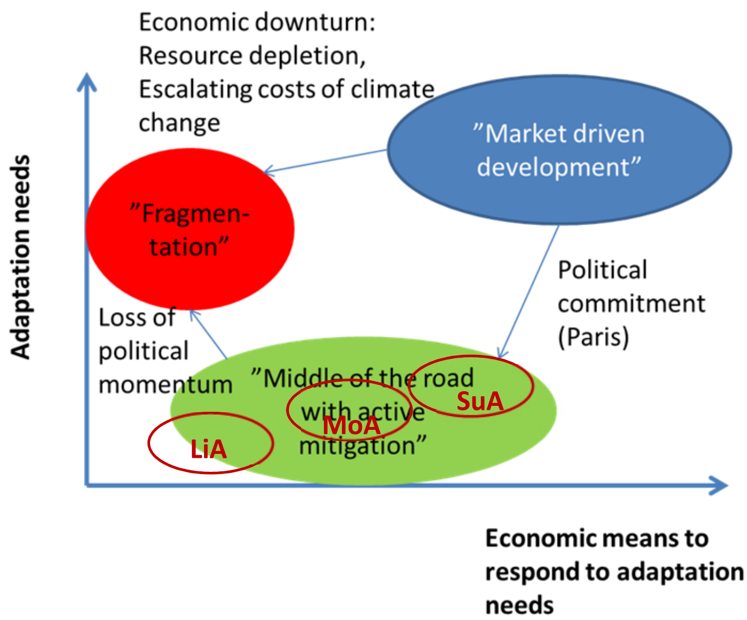


**Figure 6.9-1: Kalajoki case agricultural adaptation scenarios as a part of BASE storylines**

Notes: SuA – successful adaptation in agriculture, MoA – moderate adaptation in agriculture, LiA – little adaptation in agriculture

We based our study on realistic scenarios where farmers respond to developing markets and climatic conditions by changing crops as well as land use and fertilization habits. The scenarios were developed within a project of assessing climate change and agricultural adaptation on the nutrient loading (Huttunen et al. 2015). Three climate scenarios were used in this study. All scenarios use the emission scenario A1B, in which greenhouse gas emissions are rather high in the first part of the century and start to decrease from 2050 (IPCC 2000). Comparing carbon dioxide concentrations and global temperature change between the SRES and RCP scenarios, SRES A1B is similar to RCP 6.0 (Climate Change Impacts in the United States: The Third National Climate Assessment, 2014).

One of the climate scenarios is the Mean A1B scenario, which is an average scenario calculated from 19 global climate models for Finland by the Finnish Meteorological Institute (Ruosteenoja et al. 2007). The other two scenarios are from Regional Climate Models (RCMs) obtained from the ENSEMBLES database (van der Linden and Mitchell 2009). The scenarios were HIRHAM-ARPEGE-A1B (referred to as the “dry” scenario since the precipitation increase is small) and RCA3-HadCM3-A1B (referred to as the “wet” scenario since the precipitation increase is large). These two scenarios were selected from a larger ensemble of RCM scenarios to represent the uncertainty associated with climate change. The greatest difference in the results was obtained with regard to changes in precipitation and therefore the RCM scenarios were selected from the high and low ends of the range of projected precipitation change.

The climate scenarios were calculated as monthly changes in average temperature (°C) and precipitation (%) for the periods 2010-39 and 2040-69 compared to the control period 1971-2000 (Ruosteenoja et al. 2007). Precipitation increase by 2040-69 compared to 1971-2000 was 11.5% in the Mean A1B scenario, 4.7% in the dry scenario and 16.2% in the wet scenario. Corresponding temperature increases were 3.2, 2.6 and 2.5 °C, respectively.

In addition to the climate change scenarios, we chose a baseline and three socio-economic scenarios of agricultural adaptations and change for 2014-2050. Agricultural adaptation scenarios are described in full in Lehtonen (2015). In adaptation scenarios the fertilization level may exceed the limits in present subsidies policy.

**The Baseline.** In this “business as usual” scenario climate change effect is included, but yields, fertilizer amount, crop distribution and agricultural policy are assumed to stay unchanged. In this scenario phosphorus fertilizer is not applied in the fields with high P-status as it is limited in the subsidies policy.

**Successful adaptation.** In this optimistic scenario yields increase by 30 % for cereals and grasslands (0.9% a year) and by 60% for oilseeds and winter cereals in 2013-2050. Prices, policies, research and development imply an effective adaptation, including new cultivars suitable for a longer growing season. Higher crop yield levels are also driven by increased fungicide use for cereals, and liming which brings the soil pH up. Also drainage and soil structure investments are assumed to be encouraged by subsidies.

**Moderate adaptation.** Yields increase linearly by 10% between 2013 and 2050 (0.25 % per year). Prices and policies are the same as in the baseline. However, the moderate market prospects and yield increase imply higher needs of liming and drainage investments on specialized cereals farms, which also utilize new cultivars. The policy environment does not encourage a large group of part-time unspecialized farmers in such investments. Little subsidies are paid for farmers to aid risk management.

**Little adaptation:** Adaptation is rare even if some individual farms can avoid cereals yield reductions, with the help of some adaptations based on fungicide use and liming. Since adaptations at the farm and crop level are rare, yields decrease by 10% on both cereals and grasses, which is the opposite change in yields compared to the “Moderate adaptation” -scenario. No increase in real prices of cereals, meat and milk products from the baseline level is expected. Also agricultural policy does not encourage productivity improvements in crop production.

The adaptation is here considered in two phases. In agricultural sector we used three scenarios: successful, moderate and little adaptation. In addition we estimate the effect and cost-effectiveness of nutrient mitigation measures in river basin management plans under these scenarios.

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

**What are the alternative adaptation measures?**

In this case study we evaluate climate change effects to ecological status of waters. Already the flooding causes exceeding nutrient loads to water bodies in the case area.

We focus on agricultural sector, especially cultivation, which is most likely to be the most affected by climate change and other changes in future.

Changes in hydrologyTable 6.9-1 shows the VEMALA model simulated changes in hydrological variables between present climate (2001-2010) and decade 2051-2060 simulated under the Mean A1B climate change scenario. In Kalajoki watershed, the observed precipitation increase during 2001-2010 has been more drastic than Mean A1B scenario predicts, therefore annual precipitation is increasing only by 2% until 2060. In A1B scenario the temperature is predicted to increase by 1.6 °C until 2060. Due to the reasonable increase in temperatures, evapotranspiration is increasing by 14%. As the result of only slight precipitation increase and higher evapotranspiration increase, the annual discharge is decreasing by -5% in Mean A1B scenario in Kalajoki watershed. The decrease in runoff and discharge is the main factor explaining the changes in nutrient loading, as well as increase in denitrification from soils. However, there will considerable seasonal shift in runoff in climate change conditions. Runoff will increase during the winter months by 57…97% and decrease in during the spring (-27…-23%) and summer (-45...-15%) months (Table 6.9-2).

**Table 6.9-1: Annual changes in hydrological variables between present climate (2001-2010) and decade 2051-2060**

| | Reference (1971-2000) | Present (2001-2010) | Mean A1B (2051-2060) | Change 2001-2010 vs. 2051-2060, % (°C) | Wet (2051-2060) | Dry (2051-2060) |
|---|---|---|---|---|---|---|
| Precipitation, mm $yr^{-1}$ | 580 | 630 | 640 | 2 | 675 | 600 |
| Temperature, °C | 2.5 | 3.9 | 5.5 | 1.6 °C | | |
| Discharge sum, m $m^3$ $yr^{-1}$ | | 1280 | 1220 | -5 | 1400 | 1100 |
| Evapotranspiration, mm $yr^{-1}$ | | 295 | 335 | 14 | 330 | 320 |

Note: Simulated under the Mean A1B, wet and dry climate change scenarios.

**Table 6.9-2: Seasonal present discharge, TP, TN loading and its changes in climate change scenarios**

| | Discharge | | | | TP | | | | TN | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Pres. | M A1B | Wet | Dry | Pres. | M A1B | Wet | Dry | Pres. | M A1B | Wet | Dry |
| | m $m^3$ | % | % | % | tons | % | % | % | $10^3$ t | % | % | % |
| Winter | 240 | 87 | 97 | 57 | 14.2 | 198 | 191 | 149 | 0.4 | 100 | 100 | 69 |
| Spring | 547 | -29 | -23 | -27 | 53.1 | -36 | -29 | -26 | 1.2 | -39 | -36 | -33 |
| Summer | 225 | -41 | -15 | -45 | 12.0 | -26 | 31 | -33 | 0.4 | -44 | -15 | -46 |
| Autumn | 276 | -6 | 17 | -20 | 18.1 | 47 | 87 | 14 | 0.4 | 3 | 18 | -13 |
| Annual | 1288 | -4 | 9 | -13 | 97.4 | 15 | 32 | 6 | 2.3 | -12 | -3 | -16 |

It is assumed that increased nutrient load from the fields is the most apparent risk to river ecosystem and status. The climate change causes transformation in hydrology. The shifts of the agricultural policy and practice in changing climate have significant impact on nutrient loading in future. So far, agricultural sector has not taken into account the climate change adaptation or other future scenarios in a systematic way In Finland. At national level there are strategies, which are not implemented in local level.

No clear tipping points were identified within the studied agricultural and climate change scenarios. For example adaption is not clearly connected to profitability of current cultivation and crops because of the subside system. The policy makers should courage the farmers with subsidies for successful adaptation.

*Changes in TP loading*

The TP loading simulated by VEMALA from Kalajoki river to the Baltic Sea on decade 2001-2010 was 98 t yr-1. In the business as usual scenario the TP loading increased by 14 % and in the agricultural adaptation scenarios by 15–21 %. Erosion from the P-rich mineral top soil decreased. Presently, most erosion in the flat and coarse mineral soils in Kalajoki is caused by snow melt in spring, which causes a lot of surface runoff as the water is not able to infiltrate into the frozen soil. As winters grew milder in the climate change scenario, there was less snow melt in spring. Although precipitation was higher, the water was able to infiltrate in the unfrozen soil, thus causing less runoff and surface soil erosion. However, phosphorus losses from agriculture increased in all scenarios despite the decrease in mineral soil losses. Abundance of peat soils was the main reason for increased P loading in the Kalajoki watershed. As surface runoff decreased, percolation increased. Higher percolation leached more phosphorus from peat soils, where the P binding capacity is lower than in mineral soils. Differences in P load between the scenarios reflect the different P balances in soils attained in the simulations.

Although fertilization was highest in the successful adaptation scenario, reaching high yields due to the prolonged growing season and successful adaptation to the climate change compensated for the phosphorus addition.

According to the manuscript by Keto and Huttunen M. (2014) target for TP to reach good ecological status in Bothnian Bay coastal areas is reduction of TP loading by 9% from present loading (1600 t yr-1). If we assume that reduction share should be distributes equally between the catchments, then Kalajoki riverine loading should be reduced by 9% compared to the present loading. Climate and agricultural change scenarios are increasing the TP loading and requires higher reduction % to reach target loading of good ecological status.

**Table 6.9-3: Total phosphorus loading from Kalajoki watershed to the Baltic Sea and the source apportionment in 2001-2010**

| Scenario | Agriculture, t $yr^{-1}$ | natural background from agriculture, t $yr^{-1}$ | forestry, t $yr^{-1}$ | natural background from forests, t $yr^{-1}$ | scattered settlements t $yr^{-1}$ | point load, t $yr^{-1}$ | atmospheric deposition, t $yr^{-1}$ | TP loading, t $yr^{-1}$ |
|---|---|---|---|---|---|---|---|---|
| Present (2001-2010) | 68 | 3 | 3 | 14 | 7 | 2 | 1 | 98 |
| Business as usual with limited fertilization in the fields with high P-status | 87 | 2 | 3 | 13 | 4 | 2 | 1 | 112 |
| Little adaptation | 94 | 2 | 3 | 13 | 4 | 2 | 1 | 119 |
| Moderate adaptation | 90 | 2 | 3 | 13 | 4 | 2 | 1 | 114.8 |
| Successful adaptation | 88 | 2 | 3 | 13 | 4 | 2 | 1 | 113 |

Note: Business as usual and three agricultural adaptation scenarios.

*The measures to reduce nutrient loading*

The nutrient loading mitigation measures studied here include optimized fertilization, wintertime vegetation, wetlands and buffer zones. In the baseline scenario the present set of already implemented measures are taken into account. In addition we here evaluate the phosphorus loading reduction, cost-effectiveness and potential extent of additional measures.

**Step 3 - Evaluation Criteria and Method**

**Step 3a Selection of evaluation criteria**

Cost-effectiveness analysis was used in analysis of the measures. Cost-effectiveness analysis was used in analysis of the measures. The use of cost-effectiveness as evaluation method is justified since there are no estimates of the monetary benefits of improved water quality in River Kalajoki. KUTOVA-tool calculates the cost-effectiveness for wide range of diffuse phosphorus loading mitigation measures. Use of phosphorus as the effectiveness indicator is justified as phosphorus is a more common growth-limiting nutrient than nitrogen in fresh waters (Wetzel 1983, Pietiläinen & Räike 1997, Räike et al. 2003).

Measures to control the nutrient loading from agriculture are:

- Positive impacts/ effect: reduced P loading, kg
- Costs: implementation costs of the measure, EUR
- Cost-effectiveness: EUR/reduced loading

**Step 3b Selection of evaluation method(s)**

KUTOVA is a spread sheet tool developed in the Finnish Environment Institute (SYKE) to estimate the cost-effectiveness of phosphorus loading mitigation measures at catchment scale. The tool can be used to compare single measures by their cost-effectiveness or achievable phosphorus loading reduction rate. With the tool it is also possible to build cost-effective combinations of measures, where the interactions of the measures are taken into account. The tool includes 19 different measures from agriculture, forestry, scattered settlement and peat mining (Hjerppe & Väisänen 2015).

In this study KUTOVA was used to determine the cost-effective mitigation measures in agriculture and to build a cost-effective combination of measures in River Kalajoki. The calculations were done for present state as well as for climate change and adaptation scenarios in 2021-2030 and 2051-2060. The cost-effective combinations of measures were compared to the measures introduced in draft the River Basin Management Plan for 2016-2021.

We used cost-effectiveness as evaluation method since there are no estimates of the monetary benefits of improved water quality in River Kalajoki. KUTOVA-tool calculates the cost-effectiveness for wide range of diffuse phosphorus loading mitigation measures. Use of phosphorus as the effectiveness indicator is justified as phosphorus is a more common growth-limiting nutrient than nitrogen in fresh waters (Wetzel 1983, Pietiläinen & Räike 1997, Räike et al. 2003).

Uncertainties related to the cost-effectiveness calculations are analysed in KUTOVA-tool with Monte Carlo simulation and can be presented as range, standard deviation or frequency distribution of the cost-effectiveness in simulations (Hjerppe & Väisänen 2014).

The KUTOVA-tool utilizes the loading estimates of VEMALA model as input data. Additionally the reductions achieved with selected combinations of measures can be fed back into the VEMALA model for the calculation of impacts in receiving waters (Figure 6.9-1). For cost-effectiveness calculations we used the mean A1B scenario loading figures as a presumption and the dry and wet scenarios' loading figures as minimum and maximum values in uncertainty analysis.

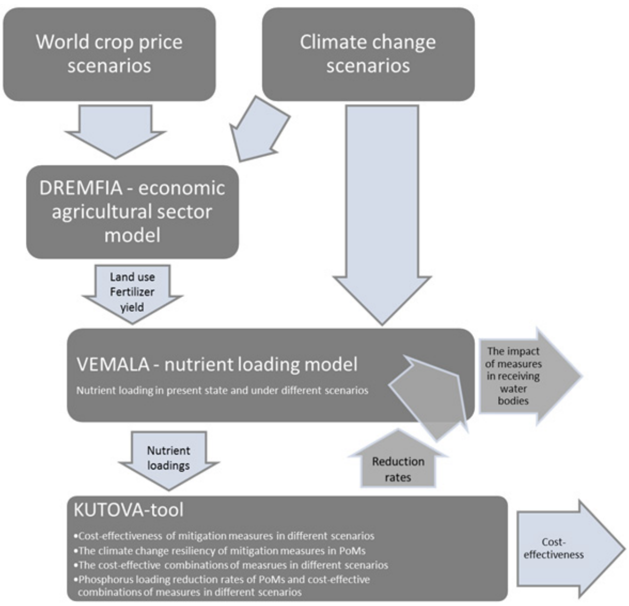


**Figure 6.9-2: Scheme of the assessment of the climate and agricultural change on nutrient loading**
Note: The feedback from KUTOVA to VEMALA was not performed in this study.

**Step 4 - Data collection**

**What are the costs and what are the benefits of the alternative adaptation options?**

CEA is based on the model KUTOVA developed by SYKE (Hjerppe & Väisänen 2015). Economic agricultural sector model DREMFIA is used for modelling of the economic scenarios for the agricultural sector. Nutrient loading model VEMALA is used for modelling nutrient load. VEMALA does not need any additional input data if used in Finland, all the needed data is already available nationally. Data is needed to estimate the effect of the measures.

**What is the evaluation time frame?**

The scenarios are calculated for 2021-30 and 2051-60.

Wetlands are the only measure in this study that has investment costs. The costs are discounted with 15-year payback period. For the other measures only annual maintenance costs are allocated.

**Which discount rate should be applied?**

In KUTOVA tool discount rate of 5 % is used. In the uncertainty analysis the discount rate is taken from an normal distribution between 3-7%.

**Which discount rate is recommended by national guidelines for climate change adaptation measures (or public investments)?**

5%

**How to deal with data uncertainty?**

Uncertainties related to the cost-effectiveness calculations are analysed in KUTOVA-tool with Monte Carlo simulation and can be presented as range, standard deviation or frequency distribution of the cost-effectiveness in simulations (Hjerppe & Väisänen 2015).

In VEMALA model there are several sources of model uncertainty: model input uncertainty, model structure uncertainty (process descriptions), model parameter uncertainty, and model technical uncertainty. In Huttunen et al. (2015, submitted) we have showed uncertainty related to the model parameters. The simulated mean TP net specific loading for 27 watersheds was 11.6 ± 0.4 kg $km^{-2}$ $yr^{-1}$ (± 4%). More variation in TP net specific loading values was found for some watersheds, e.g. 14 ± 3 kg $km^{-2}$ $yr^{-1}$ (± 24%) in Simojoki, 25 ± 2.6 kg $km^{-2}$ $yr^{-1}$ (± 12%) in Lapuanjoki and 41 ± 3 kg $km^{-2}$ $yr^{-1}$ (± 8%) in Porvoonjoki. Model structure uncertainty can be evaluated by comparing TP loading results simulated by two different VEMALA model versions – version 1 is a runoff-concentration statistical relationship based version and version 2 is more process based version.

**Step 5 – Evaluation and Prioritization**

**Agro-environmental measures**

Resilience to climate change and abilities to mitigate the negative effects of each RBM measure type has been estimated in national RBMP guidance. To evaluate the adaptive capacity of the planned agro-environmental measures we assessed the cost-effectiveness of agro-environmental measures to reduce phosphorus loading in the present state and in different scenarios (Table 6.9-1). In the climate change scenario the cost-effectiveness for all measures would be better than in the present state, in the period of 2021-2030 the price tag for reduced phosphorus would be 3-5 % smaller and in 2051-2060 19-22 % smaller. This is a result of larger share of total loading caused by the agriculture and the calculation behind KUTOVA-tool. The loading reduction of each measure is calculated with a reduction rate of the incoming loading. Thus, for example a wetland reducing 34% of the incoming loading would retain more phosphorus (in kilograms) if the incoming loading is larger.

In the adaptation scenarios the cost-effectiveness of the mitigation measures varies more. For Little and Moderate adaptation scenarios so called field measures (buffer zones, winter time vegetation and perennial grass) are not as cost-effective as they are now. In these scenarios the share of perennial grass is already high, but the TP loading still increases, because of higher percolation in peat soils. This means that these field measures cannot reduce the loading as effectively than in the present state. The cost-effectiveness of wetlands, controlled drainage and optimal fertilization is better in these scenarios than in present. This is mainly because of the same reason than in the climate change scenario alone, in other words because the input loading is increasing and the reduction of the measures is announced as per cent in the calculation. In the successful adaptation scenario all the measures would be more cost-effective in future than they are now.

**Table 6.9-4: The cost-effectiveness (EUR/P kg) of the agro-environmental measure in present and the per cent change of cost-effectiveness in different scenarios.**

| | | Cost-effectiveness | Per cent change in cost-effectiveness | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Present state | The Baseline | | Little adaptation | | Moderate adaptation | | Successful adaptation | |
| | | (EUR/P kg) | 2021-2030 | 2051-2060 | 2021-2030 | 2051-2060 | 2021-2030 | 2051-2060 | 2021-2030 | 2051-2060 |
| Buffer zones | Slope < 0.5% | 11 892 | -4 % | -20 % | 15 % | 78 % | 5 % | 73 % | -12 % | -30 % |
| | Slope 0.5-1.5% | 1 477 | -4 % | -21 % | 13 % | 71 % | 4 % | 66 % | -12 % | -30 % |
| | Slope 1.5-3.0% | 470 | -4 % | -21 % | 13 % | 71 % | 4 % | 65 % | -12 % | -30 % |
| | Slope 3.0-6.0% | 104 | -3 % | -21 % | 13 % | 71 % | 4 % | 65 % | -12 % | -30 % |
| | Slope > 6.0% | 44 | -3 % | -21 % | 13 % | 70 % | 4 % | 66 % | -12 % | -30 % |
| Small constructed wetlands (<0.5 ha) | 20-30% of catchment is fields | 617 | -4 % | -21 % | -10 % | -25 % | -10 % | -24 % | -8 % | -24 % |
| | 30-50% of catchment is fields | 351 | -4 % | -21 % | -10 % | -26 % | -11 % | -24 % | -8 % | -24 % |
| | over 50% of catchment is fields | 184 | -4 % | -21 % | -9 % | -25 % | -10 % | -24 % | -8 % | -23 % |
| Medium constructed wetlands (0.5-2 ha) | 20-30% of catchment is fields | 531 | -4 % | -21 % | -9 % | -25 % | -11 % | -25 % | -8 % | -24 % |
| | 30-50% of catchment is fields | 305 | -3 % | -22 % | -9 % | -25 % | -10 % | -25 % | -8 % | -24 % |
| | over 50% of catchment is fields | 167 | -5 % | -22 % | -10 % | -26 % | -10 % | -25 % | -8 % | -24 % |
| Large constructed wetlands (> 2ha) | 20-30% of catchment is fields | 347 | -5 % | -22 % | -10 % | -26 % | -11 % | -25 % | -8 % | -24 % |
| | 30-50% of catchment is fields | 231 | -4 % | -22 % | -10 % | -26 % | -11 % | -25 % | -8 % | -24 % |
| | over 50% of catchment is fields | 138 | -4 % | -22 % | -9 % | -25 % | -11 % | -25 % | -8 % | -24 % |
| Winter time vegetation cover | Slope < 0.5% | 1 769 | -3 % | -20 % | 15 % | 72 % | 4 % | 68 % | -12 % | -29 % |
| | Slope 0.5-1.5% | 1 068 | -3 % | -20 % | 14 % | 72 % | 5 % | 67 % | -12 % | -29 % |
| | Slope 1.5-3.0% | 616 | -4 % | -20 % | 13 % | 71 % | 4 % | 66 % | -13 % | -30 % |
| | Slope 3.0-6.0% | 272 | -3 % | -19 % | 14 % | 73 % | 5 % | 67 % | -12 % | -30 % |
| | Slope > 6.0% | 144 | -4 % | -20 % | 14 % | 73 % | 5 % | 67 % | -12 % | -30 % |
| Perennial grass | Slope 1.5-3.0% | 2 729 | -3 % | -20 % | 16 % | 86 % | 7 % | 80 % | -12 % | -30 % |
| | Slope 3.0-6.0% | 149 | -4 % | -21 % | 13 % | 69 % | 4 % | 65 % | -13 % | -30 % |
| | Slope > 6.0% | 60 | -3 % | -20 % | 13 % | 71 % | 5 % | 65 % | -12 % | -30 % |
| Controlled drainage | | 3 957 | -4 % | -21 % | -11 % | -25 % | -10 % | -25 % | -8 % | -23 % |
| Optimal fertilization | | 1 261 | -3 % | -21 % | -11 % | -29 % | -11 % | -28 % | -7 % | -22 % |

We also evaluated the effectiveness of the agro-environmental measures in the current river basin management plans and for cost-effective combinations of measures in all scenarios in River Kalajoki catchment. All measures compatible with the KUTOVA-tool mentioned in Programmes of Measures were entered into the tool. Then the total costs of the PoMs and phosphorus reduction rates of these measures were calculated. These total costs were set as a budget constraint for a cost-effective combination of measures, and measures were added to the combination.

The climate change is likely to increase TP loading in the future (The baseline scenario), in addition both the planned mitigation measures and the cost-effective combination of measures would struggle to achieve the current loading level, not to mention the target level of good ecological status (Figure 6.9-3). From the agricultural change scenarios the successful adaptation would best compensate for the increase of TP caused by climate change. Even though, the current loading level could not be achieved in 2051-2060.

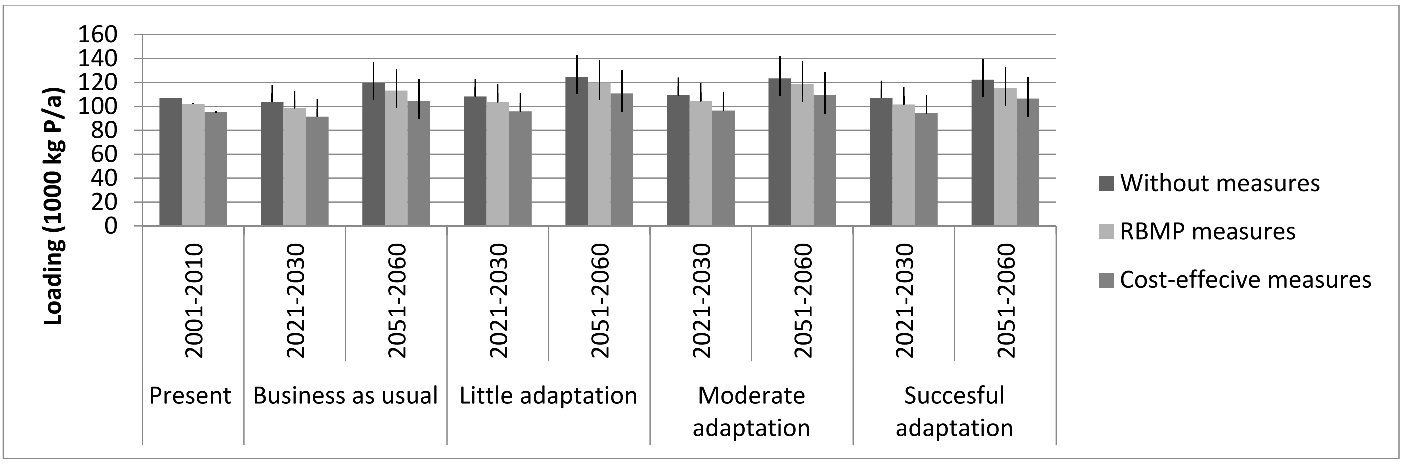


**Figure 6.9-3: Average total phosphorus (TP) loading per year in different scenarios for 2021-2030 and 2051-2060**
Note: The black lines represent the difference in climate scenarios and uncertainty related to the measures' effectiveness evaluation.

Stricter restrictions in fertilizer and especially manure application are needed for peat soils to prevent phosphorous leaching.

In the business as usual scenario P fertilization was restrained in the soils with high P status, but this was not the case in the agricultural change scenarios. Due to the large area of potato cultivation in Kalajoki, the P status is high in many field plots, and some decrease in TP loading could be obtained by not fertilizing these plots. This is why the "business as usual" scenario resulted in less increase in TP loading than the agricultural change scenarios. However, in reality potato is fertilized with relatively high amounts of P even when the P status of the field is high. Adding cereals without P fertilization in the crop rotation with potato could help in bringing the high P status of potato fields down.

The TN loading could slightly decrease in the future due to the decrease in runoff and due to the predicted decrease in cattle farming in Ostrobothnia region. Climate and agricultural change scenarios are not increasing the TN loading and TN target loading of good ecological status can be reached, in case if agriculture has sustainable development or there is no changes in the agricultural sector. However, in case in climate change scenario, where runoff would increase there is a possibility of increasing TN loading, therefore during the future studies there is a need for investigating of more extreme climate change scenarios on nutrient loading and agricultural change.

## What are the main lessons learnt from your case study?

The case study gives a framework how to take climate change more coherently into account in river basin management. By combining hydrological models and socio-economic scenarios for agriculture we can predict the changes in nutrient loading in future and reflect the adaptive capacity of the measures to control the nutrient loading. The results of analysis show that nutrient loading and therefore need for mitigation measures and their cost-effectiveness are changing due to the combination of climatic factors and agricultural adaptation level. There is a need to take complexity of the nutrient loading change and reduction possibilities into account when making long-term decisions.

According to our results, the TP loading from agriculture to water bodies is likely to increase in the future. Climate change will alter the routing of runoff in agricultural soils due to changes in snow accumulation and soil frost. Surface runoff will decrease and percolation will increase leading to more phosphorus leaching from peat soils. Stricter restrictions in fertilizer and especially manure application are needed for peat soils to prevent P leaching. However, the amount of peat soils in the Kalajoki catchment may be overestimated in the simulations, as all organic soils were simulated as peat soils. In reality, in some of the organic soils the peat layer has diminished during the decades of cultivation, so that the underlying mineral soil has eventually been mixed with the organic matter. This increases the P binding capacity of the soil, and probably decreases P loading. However, with the current version of the ICECREAM model we were not able to simulate these soils.

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The currently planned river basin management plans are not climate-proof as they seem not to be able to meet the target TP loading reductions in the future. The measures presented in draft RBM plans are not sufficient enough to tackle the current TP loading, and even less under changing climate. This underlines the need for new and more efficient measures in the future.

On the basis of our results we suggest that as the loading during autumn and winter is increasing the mitigation measures should be targeted to avoid the erosion in steepest fields. In other words these fields should be vegetated throughout the winter. In River Kalajoki there is lots of cattle farms and the problem is that the manure is not spread where fertilizers are needed but only to the vicinity of the farm. New techniques are needed for separating phosphorus and nitrogen from the manure and spreading it where needed.

The agricultural change scenarios all imply into higher TP loads in the future. The successful adaptation scenario would cause least increases in the loading and on controversy the unsuccessful adaptation would cause the highest TP and TN loading increase. Therefore farmers should be encouraged to adapt to climate change by investing in new cultivars, soil structure improvement measures like drainage, liming, crop protection measures. New policy instruments to encourage farmers to reach higher yields and bring down nutrient surplus in soils are needed. Also the mitigation measures would be most cost-efficient and effective in the successful adaptation scenario.

The weakness of the KUTOVA-tool is that cost-effectiveness in relation to phosphorus does not take into account the social acceptability of the measures nor any other aspects other than the effectiveness in reducing phosphorus loading. The tool also measures the effectiveness in terms of the “pressure reduction” (i.e. the amount of phosphorus released into surface waters) not the “impact reduction” (i.e. the reduction in phosphorus concentration in the water).

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## 6.10 Holstebro, Denmark

Anders Branth Pedersen, Helle Ørsted Nielsen, Mette Termansen, Marianne Zandersen, Jakob Stoktoft Oddershede, Aarhus University

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

**What is the climate change related problem/risk you would like to reduce by adaptation?**

The problem addressed in the Holstebro case study is flooding due to precipitation. Both Holstebro Municipality and parts of the island of Lolland are situated in those risk areas that Denmark has appointed following the guideline in EU's Directive 2007/60/EC (Ministry of Environment and Ministry of Transport 2011) and based on scenarios from the IPCC and the Danish Meteorological Institute. The main problem in Holstebro is that the watercourse Storåen runs through Holstebro City and floods the city when there are e.g. extreme precipitation events, which threatens buildings, infrastructure etc. in the city. Some Holstebro farmers might also experience flooding problems on their fields during same type of events – 29% of the farmers in the Holstebro survey reports that they have experienced increased frequency of extreme precipitation during the years they have been working on their current farm (see below).

Holstebro City experiences severe flooding events app. every 9th year. Floodings have happened due to snow melt and/or longer periods of rain filling up the natural reservoirs and increasing the water level in Storåen. On the other hand, local cloudbursts (defined by more than 15 mm in 30 mins.) haven't been causing flooding problems (Aarhus University 2014:18).

The municipality is currently protecting the city from flooding by: Regulating the watercourse according to the legislation; assessing sewers (non-structural measure, see BASE D6.1 table 1); climate adapt public buildings when they are renovated (structural measure); include flooding related prevention in the local planning process (non-structural measure); participate in development and transversal cooperations on physical measures to delay water upstream Holstebro city (non-structural measure) (Holstebro Municipality 2014b).

Denmark expects more extreme precipitation and more precipitation in general (in particular during winter – during summer precipitation is expected to decrease). In the optimistic scenario (IPCC's RCP2.6 scenario) average precipitation changes will be 1.6% from the reference period (1986-2005) to 2081-2100. In the high scenario (RCP8.5) average changes will be 6.9% (Danish Meteorological Institute & Ministry of Climate, Energy and Building 2014). Consequently, the flooding risk for Holstebro is expected to increase over time.

The watercourse Storåen has a very narrow passage in the city of Holstebro (see photo above). Consequently, during heavy rainfall, snow melting etc. Holstebro city is flooded. Last severe incident was January 2011, which was the most severe incident since 1970. Climate changes are expected to affect precipitation in Holstebro city by causing more precipitation during winter and less during summer. During summers there can be both periods with drought and periods with heavy rainfalls. Holstebro will have to prepare for: Cloudbursts, extreme run-off due to long rain periods, extreme run-off due to sudden snow melting. Additionally, it is expected that the water table will rise over the next 100 years and sea level will increase 30-140 cm what will increase the flooding problems (Holstebro Municipality 2014a). Flooding events are expected to become more frequent and more intense. Holstebro can't avoid flooding problems totally – the aim is that flooding problems will not be experienced 'too often' (ibid).

A risk map has been developed for Holstebro, where risk is defined as flooding probability and multiplied with the potential loss of value (100x100 metre squares). 'Value' consists of four parameters: (BBR-register on Danish buildings, public service functions, roads/transportation and cultural heritage). Furthermore, a flooding map has been developed for Holstebro, indicating where rainwater will store after heavy rainfalls (ibid).

Farmers might experience the flooding problems themselves but they can also be part of the solution to the problem. By letting their fields flood (upstream), in exchange for a subsidy (non-structural measure, economic incentive), they can help solving the problems in Holstebro City. Furthermore, autonomously they can adapt to a changing climate by changing crops etc.

**Which adaptation tipping points can be identified?**

A tipping point for Holstebro's flood protection would be that protection standards can no longer be met financially, as flood risk and required investments in protection are becoming too high (see BASE D6.1 table 2). There has been no assessment of when that tipping point would be reached.

**Step 2 – Identification of Adaptation Measures and Adaptation Pathways**

**What are the alternative adaptation measures?**

Holstebro's climate adaptation plan has two primary purposes: i) Overview and systematised climate adaptation efforts by mapping and prioritising focus areas, ii) holistic climate adaptation effort coordinated with neighbouring municipalities, utility companies and rescue service (Holstebro Municipality 2014a).

After the 2011 floodings in the city of Holstebro, the municipality started developing measures to cope with the problems. There are two main types of solutions: i) improve the watercourse Storåens flow through the city, ii) improve upstream water retention (ibid). Holstebro's climate adaptation plan lists 11 climate adaptation measures (see Table 6.10-1).

**Table 6.10-1: Proposed climate adaptation measures in Holstebro's Climate Adaptation Plan 2014**

| # | Measure | Purpose | Idea owner | Price | Expected effect |
|---|---|---|---|---|---|
| 1 | Widening of Storå at Storebro + increasing depth of Storå at the stretch below Storebro (structural) | Local lowering of water level in Storåen by improving the flow of water in Storåen | Holstebro Municipality | 8.8 m DKK | Minimum 4 cm lowering of water level upstream Storebro |
| 2 | Establishing bridge at overflow ramp (structural) | Local lowering of water level in Storåen by improving the flow of water in Storåen. The project was implemented 2013 | Holstebro Municipality | 0.5 m DKK | Unknown (unclear description in Holstebro Municipality 2014a, p.18). |
| 3 | Increasing depth of Storå at the stretch upstream Østrbrogade to the allotments (structural) | Local lowering of water level in Storåen by improving the flow of water in Storåen | Holstebro Municipality | 3-5 m DKK (including transportation of digged up material and protection of river banks) | Local lowering (only at the specific stretch of Storå) of water level for 600.000 DKK pr. cm |
| 4 | High water level protection at Vigen (structural) | Local high water level protection of residential area (app. 50 households) in Holstebro city. Through establishing plug wall and bank of earth. The proposed project is a matter of principle because the municipality establishes protection of private properties, if the project is implemented. | Holstebro Municipality | 1.3 m DKK excl. VAT. (costs for purchasing land or giving compensation to plot owners are not included. Neither are costs establishment of 'kontraklapper' and running the pumps) | Unknown |
| 5 | High water level protection of the Music Theatre (structural) | Protection of the municipalities own building – the Music Theatre – and infra structures towards intrusion of water from Storå. Project has been approved | Holstebro Municipality | 0.6 m DKK | Better protection of Music Theatre |
| 6 | Extended watercourse routing in Lægård Bæk and Frøjk Bæk (structural) | Lowering the hydraulic load from surface water ending up in Storå through two smaller streams. Project included in Waste Water Plan 2011-16 | Vestforsyning/Holstebro Municipality | Unknown | Retention of surface water before it reaches Storå |
| 7 | The farmer as water manager (structural (water retention, delaying, storing) and non-structural (economic incentives)) | Project collaboration to uncover agricultures role in retaining water in Storåens catchment area | Knowledge Centre for Agriculture | Unknown | Unknown |
| 8 | Local dam to retain water east of Vandkraftsøen (structural) | Avoid flooding in Holstebro city. Demands EIA and in depth analysis of consequences | Holstebro Municipality | 15-25 m DKK | Basin expected to retain up to 5 m $m^3$ of water |
| 9 | Retaining water through decentral dam solutions (structural) | Avoid flooding in Holstebro city through retention and river valleys in the municipalities of Holstebro and Herning | Vestforsyning/Holstebro Municipality | Unknown | Apparently retention of 11.28 m $m^3$ (unclear description) |
| 10 | SMS flooding warnings to citizens (non-structural) | Information service to citizens with warnings for risk for flooding | Holstebro Municipality | Unknown | Citizens with low-lying properties will have some hours to protect their property |
| 11 | Citizen report portal (non-structural) | Systematic registration of citizens' flooding experiences | Holstebro Municipality | Unknown | Unknown |

Source: Holstebro Municipality (2014a).

Notes: *Each measure is described in more detail in Holstebro Municipality (2014a). **Measure #7 is the focus of the case study. For this a number of sub-measures have been developed within the Farmer as Water Manager Network. ***Holstebro Municipality has estimated that there is a need to withhold app. 3 m $m^3$ of water (Holstebro Municipality 2014b).

The aim of Holstebro's climate adaptation plan is that flooding problems will not be experienced 'too often' (Holstebro Municipality 2014a). A business-as-usual-option would be that current protection levels are maintained – implying a risk for more frequent floodings in the future.

**Step 3 - Evaluation Criteria and Method**

**Choice Experiment Valuation Study Description**

The economic focus in the Holstebro case 'Farmers as water managers' is on cost-effectiveness of using ecosystem services on agricultural land to avoid or at least reduce impacts of inundations due to increasing amounts and intensity of precipitation. In addition a simple Cost-Benefit Analysis is carried out, comparing the nature based adaptation approach of flooding farmland with the construction of a dam to control for extreme events in order to prevent urban flooding.

The analysis is based on a choice experiment distributed in a 2014 survey to farmers in the catchment area of the watercourse 'Storåen' – Denmark's second longest watercourse. The survey was developed and implemented by Aarhus University's BASE team. The choice experiment aims to estimate farmers' willingness to participate in water management schemes by including their land in the municipality inundation planning. The experiment aims to estimate the costs of getting farmers to participate in the schemes and therefore the costs of reducing climate change problems in Holstebro.

Choice Experiments (CE) belong to stated preference methods and is based on consumer choice theory. CE simulates an ordinary trade situation in the markets where a farmer in a choice situation selects the good, characterised by a number of attributes that would bring him/her the highest utility (i.e. satisfaction). The goods are characterised by a bundle of positive and negative attributes. CE makes it possible to estimate the average preference for each of the selected attributes and for the levels of the attributes compared with one another. It also allows for a ranking or a monetary valuation of the different alternatives compared to each other.

**Step 4 - Data collection**

Attributes and their levels described in the survey include:

**Table 6.10-2: Attributes and level applied in choice experiment**

| Attribute | Level description |
|---|---|
| Restriction on crop choices | Requirement to have flood resistant crops |
| | No requirement to have flood resistant crops |
| Yearly payment for making area available for flooding under 5 year events | 500 DKK/ha (ca. 67 EUR/ha) |
| | 1,000 DKK/ha (ca. 134 EUR/ha) |
| | 2,000 DKK/ha (ca. 268 EUR/ha) |
| | 3,000 DKK/ha (ca. 403 EUR/ha) |
| Coverage of losses of crops during inundations on contracted area | No coverage of crop losses |
| | Value of crop losses assessed by professional valuer |
| Negotiation situation | Individual negotiation with your municipality |
| | Collective negotiation together with other farmers from your sub-catchment |

Farmers were asked to answer six consecutive choice cards. An example choice card is presented below:

**Table 6.10-3: Example choice card**

| | Contract A | Contract B | Status Quo |
|---|---|---|---|
| Crop choice restriction | Requirement to use flood resistant crops | No requirements to use flood resistant crops | No restrictions |
| Yearly payment for making area available for flooding under 5 year events | 2,000 DKK | 1,000 DKK | No payment |
| Coverage of losses of crops during inundations on contracted area | No coverage of crop losses | Value of crop losses assessed by professional valuer | No coverage |
| Negotiation situation | Individual negotiation with your municipality | Collective negotiation with other farmers from your sub-catchment | No negotiation |
| My Choice (pls. tick only once) | | | |

67 farmers completed the choice experiment (449 farmers were contacted). This is statistically a sufficient number of respondents to derive an estimate of social costs of initiating such a climate adaptation scheme. Of the 67 farmers, five turned out not to own the farm and were therefore excluded from the dataset. A total of 17 respondents (26,2 %) chose the non-contract option in all six choice occasions (so-called serial non-participants). This is not particularly high compared with other CE studies. We retain 62 respondents in the subsequent analysis.

**Step 5 – Evaluation and Prioritization**

Results of the conditional logit indicate that farmers on average do not prefer a contract (asc_change coefficient is positive) nor would they like to negotiate the contract individually. Farmers prefer compensation and payment, as can be expected. Requirements on specific flood resistant crops proved to be statistically insignificant.

**Table 6.10-4: Conditional Logit Regression results**

| Variable | Coefficients (Std. Errors) Protesters excluded (N=62) | |
|---|---|---|
| asc_change | 1,4810 *** | (0,2020) |
| Specific Crop Requirement | -0,0936 | (0,0768) |
| Compensation | 0,2944 *** | (0,0768) |
| Individual negotiation | -0,1244 * | (0,0756) |
| Payment | 0,0006 *** | (0,8319D-04) |
| Log-likelihood | -367,62 | |
| $\rho^2$ | 0,08 | |

Notes: *** significant at p < 0.01, ** significant at p < 0.05, * significant at p < 0.10

**Estimating monetary values based on the CE**

This regression analysis of the responses from farmers can be utilised to generate the following types of quantitative information:

- Marginal farmer willingness to accept individual attributes = public costs of paying for individual attributes in the CE (e.g. EUR/ha for having a crop restriction; EUR/ha for a yearly payment etc.);
- Average farmer willingness to accept a full contract to allow flooding on his/her land, specified in EUR per hectare. This average value indicates the public costs of having this type of adaptation measure to protect infrastructure and urban areas; and

- Ranking of farmer preferences for different contents of water management contracts.

Based on the coefficients from the conditional logit regression, we calculate both the marginal willingness to accept individual attributes of the contract and the average willingness to accept a full contract with the municipality.

The marginal willingness to accept is calculated as below, where $\beta_1$ is the attribute to be valued and $\beta_c$ is the payment coefficient, which represents the marginal utility of income. We multiply the coefficient of the attribute to be valued by 2 because all attributes with the exception of payment is effects coded (i.e. the marginal value is compared to the base level):

The two marginal farmer willingness to accept comprise the average impact on farmer utility by i) having an individual negotiation compared to having a collective negotiation and ii) a contract that allows for individual compensation of specific crop losses compared to no specific crop losses. This is calculated by taking the utility change between the baseline level and a particular characteristic of the contract (e.g. individual negotiation) and dividing it by the compensation coefficient.

$$MWTA_i = \left(\frac{\beta_i - \beta_0}{\alpha}\right),$$

where $MWTA_i$ represents the willingness to accept a contract based on an individual compensation (compensation for crop loss) compared to a collective negotiation (no compensation of crop loss). $\beta_i$ is the utility coefficient value associated with attribute $i$, $\beta_0$ the utility coefficient value of the specified baseline, and $\alpha$ represents the utility coefficient value for a unit of subsidy. The coefficient $\alpha$ is positive as people normally gain utility as the price of an attribute decreases.

**Table 6.10-5: Marginal WTA results**

| Attribute | Marginal WTA (EUR) |
|---|---|
| Individual negotiation | -59 |
| Compensation at crop loss | 139 |

This marginal willingness to accept represent the utility that farmers would obtain if a contract would consist of individual negotiation (in this case farmers would have a utility increase of 59 EUR if the negotiation were collectively made with other farmers). Likewise, if a contract would contain the possibility to have a compensation made for crop losses, assessed by an expert, this would increase the utility of farmers by 139 EUR.

In order to estimate the average the willingness to accept a full contract with the municipality, we need to comprise the share of farmers, not willing to enter a contract, otherwise the payments would not indicate a realistic average level of payments needed. The WTA of a contract is calculated by adding the coefficients of the attributes and subtracting the alternative specific constant (as this indicates opposition to the contract) and dividing by the marginal utility of income (here the coefficient of the payment attribute:

$$WTA\ of\ full\ constract = \frac{\beta_{compensation} + \beta_{negotiation} - \beta_{ASC}}{\beta_{payment}}$$

The resulting payment that the average farmer would accept range between 250 EUR and 447 EUR per ha per year depending on the conditions in the contract.

**Table 6.10-6: WTA results**

| Contract | WTA/ha (EUR) |
|---|---|
| Collective negotiation + compensation at crop loss – alternative specific constant | -250 |
| Individual negotiation + compensation at crop loss – alternative specific constant | -309 |
| Collective negotiation + no compensation at crop loss – alternative specific constant | -389 |
| Individual negotiation + no compensation at crop loss – alternative specific constant | -447 |

**Cost Effectiveness of the measure 'Farmers as Water Manager'**

In order to estimate cost efficiency of the measure 'farmers as water manager' (see section 1) we would need a specification of how much land would be able to retain how much water. This measure would only function as a whole, just like a dam would need to be constructed fully before it can fill out its purpose.

One of the ten options (see step 2 section) that the Municipality of Holstebro is considering to protect the town against fluvial flooding is the construction of a dam. This would entail the construction of a dam facility in the upstream area of Storå relative to Holstebro. In case of risk of flooding in Holstebro, a damper in the dam will be closed in order to hold back water until it can safely be released again. This will cause flooding upstream the dam, e.g. on farmland.

The amount of water needed to be held back for an incidence that will happen statistically once in every 100 years is estimated to be 3 m $m^3$. For a 1000-year incidence it is 5-10 m $m^3$ (Vestforsyning, 2014).

The calculated 100- and 1000-year incidences are calculated based on status quo, i.e. based on measured watercourse data in the recent past. Hence the calculations are not based on future climate scenarios and the subsequent levels of 100 or 1000-year incidences as they would appear by 2050 or 2100. The municipality is aware that although the life span of the dam is set to 75 years, this is not realistic, given that the dam is not laid out for a 100 or 1000-year incidence in 75 years. The municipality sees the construction of the dam as a preliminary short-term solution (i.e. for the next 30 years. Depending on the volume of fluvial flooding) that serves to buy time and make way for a more permanent long-term solution (75 years and longer). The municipality does not reckon that the dam would be subject to wear and tear if more than one extreme event were to follow another.

Vestforsyning (Skitseprojekt for klimasikringsanlæg ved Holstebro til magasinering af vand i Storå, 2014) suggest six similar dam constructions, which differ mainly in location. It has not yet been decided politically (as per January 22, 2015) which one to proceed with, if any. Two solutions can hold back around 3 m $m^3$ of water. The first, holding back 2,9 m $m^3$ water, would need 156 hectares of land for periodical flooding, while the second, holding back 3 m $m^3$ water, would need 148 hectares[54]. The largest suggested solution, which has capacity of holding back 4,7 m $m^3$ water, would need 200 hectares.

Assuming that the town of Holstebro would decide to construct a dam that could resist a 100 year event, cost effectiveness of the farmer as water manager would cost between 12.340 EUR and 22.070 EUR per m $m^3$ retained depending on the contractual content and dam solution. These costs only include the costs of paying farmers to retain water on their fields, not costs of the dam included (please see cost benefit analysis below).

**Table 6.10-7: Cost effectiveness of Farmer as Water Manager, 100-year event, costs per year**

| Farm land required (ha) | Retain capacity (M $m^3$) | Contract cost/ha (EUR) | Total costs (EUR) | Costs/M $m^3$ retained (EUR) |
|---|---|---|---|---|
| 156 | 2.9 | 250-447 | 39,021-69,789 | 13,455-24,065 |
| 148 | 3 | 250-447 | 37,020-66,211 | 12,340-22,070 |

**Estimations of costs and benefits of constructing a dam and flooding farmland under extreme events**

[54] The locations for the 2.9 m $m^3$ water and 3.0 m $m^3$ water are different, which may explain the higher area needed for the lowest amount of water.

Total expected costs related to a 1000 year flooding in Holstebro has been estimated by Holstebro Municipality to be 0.763 m DKK per (Holstebro Municipality, 2013). We assume numbers are in 2013-values.

The suggested dam construction would be able to withstand a 1-in-100 year incidence. Withstanding a 100-year event represents retaining an additional 17m$^3$/second (equalling a total water flow of 67m$^3$/second in Storåen). A 1-in-1000 year event has been calculated to represent an additional 17m$^3$/second more than a 100-year event (equalling a total water flow of 84m$^3$/second). With the dam construction, a 1-in-1000 year event would cause damage equalling damage costs of a 1-in-100 year event, i.e. damage costs would be significantly reduced.

In the following calculation, we compare costs and benefits of constructing a dam that can withstand a 100-year event and we assume a 1000-year event that has an interval frequency of 0.003 (Orbicon, 2013). The analysis is calculated over 75 years, which is the estimated lifetime of the dam construction. Benefits (i.e. avoided damages) remain fixed as the dam is not continuously increased as climate change effects progress. The dam is assumed to withstand a 100-year event under current climate with no wear and tear or risk of collapse during events that overflow the dam.

Given the available data, we are not able to calculate the CBA for increases in avoided damages as climate change effects progress, as we do not have data on costs of increasing the level of the dam. However, current level of damages may be more costly in future because of higher economic values involved. In order to calculate the increases in avoided damages given higher economic values, we use the average yearly development in GDP under two storylines: SSP2 and SSP5, as a proxy for the increased value. Table 6.10-8 below summarises the elements of the CBA.

**Table 6.10-8: Elements of CBA**

| Cost Elements | Value |
|---|---|
| Payment to farmers (lowest level) (EUR/ha/yr.) | 250 |
| Payment to farmers (highest level) (EUR/ha/yr.) | 447 |
| **Benefit Elements** | |
| Accumulated avoided damage costs per event (m EUR for a 1-in-100 year event) (2013 values under current climate) | 3.13 |
| Yearly avoided damage costs when avoiding 1-in-100 year events (m EUR/yr.) (2013 values under current climate) | 0.093 |
| Yearly average increase in avoided damage costs when avoiding 1-in-100 year events under SSP2 (%) * | 1.7 |
| Yearly average increase in avoided damage costs when avoiding 1-in-100 year events under SSP5 (%)* | 2.5 |
| **Other elements** | |
| Average annual growth rate of benefit values under SSP2, Denmark (%) | 1.7 |
| Average annual growth rate of benefit values under SSP5, Denmark (%) | 2.7 |
| Frequency interval of a 1000 year event (%) | 0.3 |
| Dam construction costs (capacity: 3 m m$^3$) (m EUR) | 3 |
| Area flooded (ha) | 159 |

Note: * Based on IIASA SSP Database, OECD Env-Growth Model, Denmark, SSP 2 and SSP 5 2015-2090.

We apply the Danish guidance on discount rates for long-term projects as well as 1 % and 5 % discount rates for sensitivity analysis.

Table 6.10-9 below clearly indicates that assuming current levels of avoided costs and in the event of a 1-in-1000 year flooding under a protection level for a 1-in-100 year event, adaptation costs outweigh benefits, independently of farmer level payments. These results are robust across the different discount rates applied. Applying the national decreasing discount rates, results range between -2.45 to -1.70 m EUR for high and low level farm payments respectively. This decreases but stays negative when applying a 1% discount rate and increases when applying a 5% discount rate for sensitivity purposes.

If, however, we take future economic growth and hence the increase in values of infrastructures and property into account, based on the development of GDP in Denmark under the SSP2 and SSP5 scenarios, the balance moves in favour of adaptation (i.e. avoided damages increase). This result is robust across discount rates and level of farmer payment. As SSP2 entails a lower economic growth than SSP5, net benefits are naturally higher under the SSP5 scenario. Under SSP2, positive net benefits range between 0.69 and 1.45 m EUR when applying the national decreasing discount rates (for high and low level farm payment respectively), increasing to between 6.13 and 7.77 m EUR under a 1% discount rate application and decreasing to negative benefits of 0.25 m EUR under high level payments and positive benefits of 0.35 m EUR under low level payments under a 5% discount rate. Under SSP5, net benefits are in all instances higher and positive.

**Table 6.10-9: Cost Benefit Results of Different SSP Scenarios and Discount rates (Net Present Values in m Euro)**

| Scenario | Discount rate | | |
|---|---|---|---|
| | Decreasing* | 1% | 5% |
| **Assuming current level of benefits** | | | |
| Highest compensation level | -2.45MEuro | -1.80MEuro | -2.57Meuro |
| Lowest compensation level | -1.70MEuro | -0.21MEuro | -1.97MEuro |
| **Assuming levels of benefit following economic development under SSP 2** | | | |
| Highest compensation level | 0.69Meuro | 6.13Meuro | -0.25Meuro |
| Lowest compensation level | 1.45MEuro | 7.77MEuro | 0.35MEuro |
| **Assuming levels of benefit following economic development under SSP 5** | | | |
| Highest compensation level | 1.31Meuro | 8.02Meuro | 0.16Meuro |
| Lowest compensation level | 2.06MEuro | 9.61MEuro | 0.75MEuro |

Notes: *4% (0-35 years); 3% (36-70 years); 2% (>70 years) (Danish Ministry of Finance, 2013)

It should be noted, that avoided damage costs only include direct costs (e.g. damages on different types of buildings and infrastructure) and do not include indirect costs (e.g. loss of income and health costs).

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Knowledge Centre for Agriculture

## 6.11 Kalundborg

Andreas Hastrup Clemmensen, Anne Haulgvaldstad, DBT

**Introduction**

The Municipality of Kalundborg joined the EU-Interreg project 'BaltCiCA' from 2009-2012. The BaltCICA project was set out to finding ways of dealing with climate changes in the Baltic Sea Region. Through the use of climate change scenarios adaptation, measures were to be developed in corporation between planning authorities (e.g. municipalities) and relevant stakeholders. Kalundborg thus joined BaltCICA with the purpose of taking a close look at an area located in the south-western part of the municipality. BaltCICA was considered to be one of several ways to gain the required knowledge to draw up a climate adaptation strategy for that particular area, and possibly to provide inspiration for such a strategy covering the entire municipality. In the Kalundborg case this was done by carrying out a scenario workshop with relevant stakeholders and later a citizen summit where ordinary citizens were consulted on the results of the scenario workshop.

The workshops were carried out in cooperation between the municipality and DBT. The scenarios used in the scenario workshop were developed from calculations of the future precipitation patterns and sea level rise in the case area by GEUS[55]. The goal was to clarify different and potentially conflicting interests of citizens and stakeholders in the particular area to be used in the later development of a climate adaptation strategy for the whole area of Kalundborg. In 2011, the results were analysed, debated by the politicians, and the administration started drafting up an adaptation strategy, based partly on the results from the citizen summit, partly on further assessments of climate impacts in the municipality, and partly on fairly general guidelines from government agencies and ministries.

In the retrospective case of Kalundborg Municipality three future scenarios attempt to highlight what the consequences will be of responding to deal with future climate change in different ways. The three future scenarios are: a baseline or `laissez-faire scenario´, a `protection scenario´ and an `adaptation scenario´.

The `laissez-faire´ scenario is based on the assumption that is in not desirable to do anything to alleviate the impact of future climate changes, beyond what is within immediate economic reach.  The `protection scenario´ is based on an attempt to protect current land uses as much as possible against the consequences of climate change. This includes residential areas, infrastructure, commerce and agriculture. Initiatives will be launched in order to protect existing economic interests, even if this has negative consequences for the environment and nature. The `adaptation scenario´ is based on the need to adapt to future climate changes rather than fight against them. Current land uses will be re-evaluated and adjusted to the changing environment,

In a meeting between Kalundborg Municipality and the consultancy firm NIRAS the 12th of April 2010, it was agreed that NIRAS should assist with analysis, which act as the foundation for the further scenario work. NIRAS have produced background material, which describes the four different scenarios and the expected consequences, with a description of the 24 different concrete solution ideas. NIRAS' analyses are based on IPCCs A2 scenario. For the A2 scenario in Denmark the predicted climate change for precipitation up to year 2090 include:

- 43 % increase in winter precipitation,
- 15 % decrease in summer precipitation,
- 20 % increase in extreme rain events,
- No significant change in groundwater level in the case study area.

The consultancy firm, NIRAS, have made an economical assessment for the three scenarios.

[55] Geological Survey of Denmark and Greenland

The consultancy firm has chosen the following analytical approach and defined the task as the basis for the impact assessment:

- The impact assessment is based on the four scenarios, including a wide range of effects from the 0-scenario and/or possible planned measures to counter the effects.
- Each effect or measure has a number of physical effects, which depend on the underlying assumptions in the model.
- The temporal scale is taken into account of the flooding compared to an overall estimated (aggregated) consequence of a 80-100 year time period.
- The model is a simple either-or model, where each solution or measure is analysed separately.
- The consequences of the flooding from sea level rise are analysed separately. The synergies between sea water, surface water and changes in ground water level is not taken into consideration.
- Each physical consequence has an economic consequence as each measure is associated with a cost. The damage costs and costs of implementation are presented without a discount rate but presented with either undiscounted fixed or annual values.
- For each scenario the economic consequences of the effects of the 0-solution and other measures are analysed. In the 0-solution operation loss of agricultural land are not accounted for.

**Calculations of damage costs**

*0-Scenario- `laissez-faire scenario´*

The ´laissez-faire scenario´ can be defined as the consequences on water supply, infrastructure, residential areas, nature, landscape which follow the expected climate change, if nothing is done to mitigate the consequences.

In 2090 the damage costs of residents and summer cottages are estimated to a minimum of 110 m DKK every 10 years due to extreme sea level events. The total undiscounted risk weighted damage costs from 2010 to 2090 are estimated to 250 m DKK for summerhouses, 800 m DKK for residents and 50 m DKK for farm property.

The consultancy firm NIRAS have analysed the economic assessment of roads affected by flooding. The damage costs are dependent on flood duration, associated with time loss due to waiting time, detour etc. during the time the road is flooded. There are therefore large uncertainties in the calculation of the concrete  Costs connected to the building of a new road is between 5 to 7 m DKK per km.

Coastal erosion will affect summer cottages, farmland area and protected nature areas in the case study area. It is estimated that approximately 12 ha farmland corresponding to a cost of approximately 2 to 3 m DKK and a small nature area, which has not been priced, will be lost.

The accumulated cost of damages to private properties by 2090 is estimated by NIRAS to be approximately 242 m EUR (Municipality of Kalundborg, 2011).

The outcome of the scenario workshop was the development of four different visions:

1. Transforming the area into a nature area
2. Phasing out vulnerable properties but allowing interim protection
3. Establishing onshore and river dikes
4. Construction of large offshore dikes
5. Of the four visions, protection based on offshore dykes and transforming the area into a nature area were the most radical and controversial solutions in the eyes of the Kalundborg administration.
6. After the scenario workshop a consultancy firm, NIRAS, were involved in estimating the economic costs of implementing the adaptation options in the visions drawn out by the stakeholders.

**Table 6.11-1: Scenario A - 0-scenario**

| Impacts<br>Water supply | Nothing is done (0-scenario) | Costs in year 2090 (undiscounted) |
|---|---|---|
| Approach to groundwater changes | No impact | |
| Approach to fresh supply water changes | 5 m $m^3$/year water reduction in the obstruction process | 45 m DKK yearly |
| **Infrastructure and buildings flood** | | |
| Summerhouses (number affected) | Permanently not usable: 503; Not usable every 10 years: 1078; Not usable every 20 years: 1368; Not usable every 40 years: 1520; Not usable every 100 years: 1700 | 750 m DKK |
| Residential (number affected) | Permanently not usable: 112; Not usable every 10 years: 175; Not usable every 20 years: 190; Not usable every 40 years: 204; Not usable every 100 years: 215 | 950 m DKK |
| Farms: Production/farmhouses (number affected) | Permanently not usable: 10/2; Not usable every 10 years: 25/7; Not usable every 20 years: 27/8; Not usable every 40 years: 44/10; Not usable every 100 years: 44/11 | Not calculated |
| Roads | Road by Gørlev every 10 years | Not calculated |
| Reersø not accessible during periods | Daily | Not calculated |
| Coastal erosion | Loss of area: 0.12 km2 farm land; 0,09 km2 nature; 0,14 km2 built areas; buildings lost: 9 summer houses | 2-3 bn DKK (only farm land) |
| **Changes in environment and nature** | | |
| Affected Natura 2000 areas | Tissø will lose species; Reduction or loss of dune by Flasken; Marsh moves into the land; inland beach becomes lagoon | Not calculated |
| Nutrient leaching from agricultural soils | Not evaluated | Not calculated |
| **Landscape changes** | | |
| New permanent wetlands | Because the areas along rivers and the coast will not be able to be used for agricultural purposes, the areas will change character and become wetlands and meadows. | Not calculated |
| New summer cottage areas | Not relevant | Not calculated |
| View of dikes | Not relevant | Not calculated |
| Loss of recreational value | The recreational areas will change character from a summer cottage areas to a nature area. | Not calculated |

*Scenario B- Gradual Adaptation*

The planned actions are defined as a number of diverse initiatives, which all aim at built-up areas are protected in the short term but in the long run at converted for the benefit of environmental restoration. Reersø, Bjerge Sydstrand and Bjerge Nordstrand are protected so they are converted in 70-100 years. The consequences of changed water supply, infrastructure, settlements and the environment, nature and landscapes is assessed as a result of each of the actions planned separately, while the other measures are kept constant. Synergies between different initiatives were not analysed.

The impact assessment is based on the 0-scenario and describes the effect of individual adjustments for the 0-scenario and the related financial consequences.

For each action, a rough estimate of the related costs, as well as the saved damage costs is calculated. An overview can be seen in the table below.

*Scenario C- The protection scenario*

The planned protective measures either involve the creation of two large sea dikes from Reersø to Mullerup Havn to the south and Svallerup Strand to the north, or the establishment of new coastal dikes along most of the coastline and onshore dikes along most of Nedre Halleby Å.

The impact assessment is based on the 0-scenario and describes the effect of individual adjustments for the 0-scenario and the related financial consequences.

For each action, a rough estimate of the related costs, as well as the saved damage costs is calculated. An overview can be seen in the table below.

**Table 6.11-2: Scenario B - Gradual adaptation**

| Scenario | Description | Requirement for calculating the costs of action | Saved damage costs |
|---|---|---|---|
| Local dikes | Construction of natural/artificial dikes by Mullerup, Dabldy Strand and Ornum to protect the areas Bjerge Sydstand, Bjerge Nordstand and Reersø. The dikes will be fased out after 70-100 years. The overall idea is that the built area will be protected on a short time scale but not on the long time scale for the benefit of restoration. | Total construction costs for the dikes = 161 m DKK. Total costs for pump systems are estimated to 100 m DKK. | The dikes can withstand a 100 year scenario, and the damage costs connected will be saved. The undiscounted damage costs is 1,7 bn DKK. Based on the yearly undiscounted accumulated damage costs will exceed the construction costs by 2045. (Farmland is not included) |
| Dike road | Construction of a dike road/bridge to Reersø in 3.8 m DVRm. | Construction of 4.5 km dike with a road (10 km width with bicycle lane). Total costs = 63 m DKK | More information required |
| Vulnerable houses on stilts | The most vulnerable houses and summerhouses (Bjerge Sydstand) are moved up on stilts. | The most vulnerable houses are those that in 2090 will be flooded every 10 years. The additional cost of building on stilts is app. 690 m DKK. In addition there are new construction costs. | 480 m DKK (farms not included) |
| Vulnerable houses on Bjerge Sydstand get moved | The most vulnerable summerhouses are moved into the countryside. Replacement areas for those areas, which will be lost the next hundred years are pointed out. | The total additional costs are 38 m DKK plus costs for new construction. | |
| Bjerge sydstand houses are demolished | The most vulnerable summer houses are demolished | 38 m DKK. In addition the value of the summerhouses is lost. | 488 m DKK are saved in damage costs by the demolition of houses and summer houses |
| Tissø is closed with counter-current lock by Halleby Stream | Tissø is held free of salt by the help of a lock by Halleby Stream where | 3-5 m DKK | The maintenance of process water supply gives spared damage costs to 45 m DKK yearly in 2090 |
| Tissø is closed with a lock by Lille Åmose | Tissø is closed with a lock, Lille Åmose will function as a rainwater reservoir. | Implementation costs regarding the adjustment of the work is estimated to cost between 3-5 m DKK. Assuming that a new pumping station and supply | Saved damage costs are app. 34 m DKK yearly in 2090. |

| | | | |
|---|---|---|---|
| | | conduit estimated to cost 16 m DKK including 20% uncertainty. | |
| Store Åmose and Bøstrup Mose as rainwater reservoirs. | Used as rainwater reservoirs to minimise flooding by the coast | The total costs are app. 1.8 m DKK yearly | Calculations of the saved costs require detailed hydrological analysis |
| Reestablishment of streams | The natural course of streams are re-established | Information is needed for which streams to re-establish | |
| New artificial water reservoirs | Costs in the form of lost soil rents 3.1 m DKK yearly | | |
| Helsinge river valley as permanent wetland | Conversion to a permanent wetland | Total costs app. 0.6 m DKK yearly | Calculations of the saved costs require detailed hydrological analysis |

**Table 6.11-3: Scenario C - Protection with dikes and pumps**

| Scenario | Description | Requirement for calculating the costs of action | Saved damage costs |
|---|---|---|---|
| Construction of two sea dikes | Built-up areas, summerhouse areas, farmland, infrastructural areas and natural and environmental areas shall be maintained as it is today on short and long term. This will be done by the construction of two sea dikes in the north and south of Reersø. | Total costs of dikes and locks are estimated to 0.6 bn DKK. | Saved damage costs by avoiding flooding of summer houses and homes is app. 1 bn DKK (undiscounted). Securing process water feed gives saved damage costs to app 45 m DKK yearly |
| Dikes close to shore | Coastal areas, farmland and summerhouse and residential areas are protected by constructing dikes and pumps. | Total implementation costs calculated to app. 110 m DKK. The implementation of a new outlet is estimated to costs between 5-10 m DKK. Total implementation costs of pump systems are app. 100 m DKK. | Total saved damage costs are app. 1.7 bn DKK. The yearly undiscounted accumulated damage costs will exceed implementation costs by 2044. In 2044 it will be beneficial to build dikes and pump stations. |
| Onshore dikes and new canal | Establishment of stream dikes combined with coastal dikes to control the drainage of areas around canal. Stream dikes will be established and the inlet from Tissø will be controlled so pumping stations can control the drainage. | | |

**Economical background data sent out to the participants prior to the citizen meeting**

Prior to the citizen meeting held in March 2011, the participants received background information including an economical assessment based on societal and construction related costs of different adaptation strategies for the case specific areas of Reersø/Tissø. The purpose of the economic data was to prepare the citizens for the discussions and voting during the citizen meeting.

Below is a summary of the economic data the citizens received prior to the citizen meeting.

The total cost of an 80 cm sea-level rise in the period 2010 to 2090 is estimated to 1.8 bn DKK. In addition direct and indirect costs are associated with damage on roads and delay etc. Even more, environmental problems are not priced. The participants received an economic estimate of the costs of the four alternative solutions for adaptation in the area, which were developed at the scenario workshop. The alternative solutions included:

1. Offshore dikes
2. Large dikes on the coast and land
3. Phasing out of vulnerable areas with human settlement during this century
4. Quicker conversion to natural areas (no temporary protection)

*Solution 1: Sea-dikes*

**Table 6.11-4 Economic considerations associated with solution 1**

| Solution 1 | Costs | Saved damage-costs (including water abstraction) |
|---|---|---|
| Offshore dike with high water level locks | 0.6 bn DKK | 2067: 0.6 bn DKK<br>2090: 1.1 bn DKK |
| Offshore dike with locks and pumps | 0.61 bn DKK | 2067: 0.61 bn DKK<br>2090: 1.8 bn DKK |

*Solution 2: Large dikes on the coast and land*

**Table 6.11-5 Economic considerations associated with solution 2**

| Solution 2 | Construction costs | Total saved damage-costs |
|---|---|---|
| Coastal dikes | 127 m DKK | |
| Dikes along Nedre Halleby Stream | 39 m DKK | |
| New outlet for Nedre Halleby Stream north Bjerge Sydstrand | 5-10 m DKK | |
| Counter-current lock in Nedre Halleby Stream | 3-5 m DKK | |
| 4 pump stations in connections with coast dikes | 5-30 m DKK | |
| **Total costs** | 275 m DKK | 2045: 280 m DKK<br>2090: 1.8 bn DKK |

*Solution 3: Phasing out of vulnerable areas with human settlement during this century*

The overall idea is that exposed property will in a controlled manner be phased out the next 50 to 100 years in favour of a gradual adaptation to water and wetland areas. The solution will on a longer time scale mean that the value costs protected in solution 1 and 2 will be lost. This raises the question of compensation as the owners are gradually prevented in protecting their property.

*Solution 4: Quicker conversion to natural areas (no temporary protection)*

The aim of this solution is to take advantage of climate change in order to strengthen nature in the landscape. This solution implies that exposed property will be phased out. The solution will mean that the value costs protected in solution 1 and 2 will be lost.

The results and recommendations from the citizen meetings did not have direct influence for the municipality's strategy and implementation of climate change adaptation. From the beginning it was made clear to all participants that input from stakeholders and citizens was to be part of the decision making process on equal footing as other input.

**Climate Strategy and its implementation - Climate Change Adaptation Plan for Kalundborg Municipality**

In 2013 the Kalundborg administration finished a climate adaptation strategy for the municipality to map the future flood risk from rainfall, sea and ground water in order to take account climate change adaptation in the forward planning. The plan also identified physical actions where either the risk of flooding is high or where the socio-economic values at stake are so high extra effort to protect the area is necessary.

To identify the areas which should be prioritized for the implementation of climate change adaptation in the Kalundborg the municipality created a risk-based methodology to qualitatively assess flood risk based on hydrological models, land-use data and socio-economic data.

In order to meet the local council's overall goal of adapting to climate change is most appropriately the municipality want to focus efforts on the areas at greatest risk. The municipal effort can thereby focus on the areas where there is the most need. The municipality have identified a list of physical areas out of a 12-year municipal perspective. Because not all flood-prone areas can be protected during the 12-year planning period, it has been necessary to prioritize the choice of areas to focus on. In the prioritization of the areas, following criteria have been used:

Risk of flooding, property price, connection with other plans and projects and special values for the municipality. To support the planning and prioritization three types of maps have been made for Kalundborg:

- Flood mapping
- Value cost mapping
- Risk mapping

The flood mapping visualizes were the damage will occur. The value mapping shows which values will be affected. The risk mapping combines the two maps to one map, and visualized how the planning can be prioritized, partly based on where the risk is the biggest and partly on where the areas with the most value are located.

As a consequence of flooding the larges socio-economic loss is typically connected to damage costs of buildings. In the case of Kalundborg, property values are the only parameter incorporated in the climate adaptation plan's value mapping. A cost value map was constructed, which shows where the concentration of property values is greatest for the areas, threated by flooding.

Results from the citizens meeting in 2011 (BALTCICA) showed, that the majority of the citizens feel, that the municipality should engage in dialog with landowners regarding climate change and adaptation, and should contribute with knowledge, expertise and help with financing. The value mapping insures that the municipality's efforts are optimally prioritized.

The risk map is generated by combining the flood map for a 5-, 10-, 20-, 50- and 100-years event for storm-surge and a 50-year event for cloudburst with the value map. A weighted map which shows the total risk is produced, where by the risk is either very high or the threatened property values are very high. On the basis of this map the effort areas are selected.

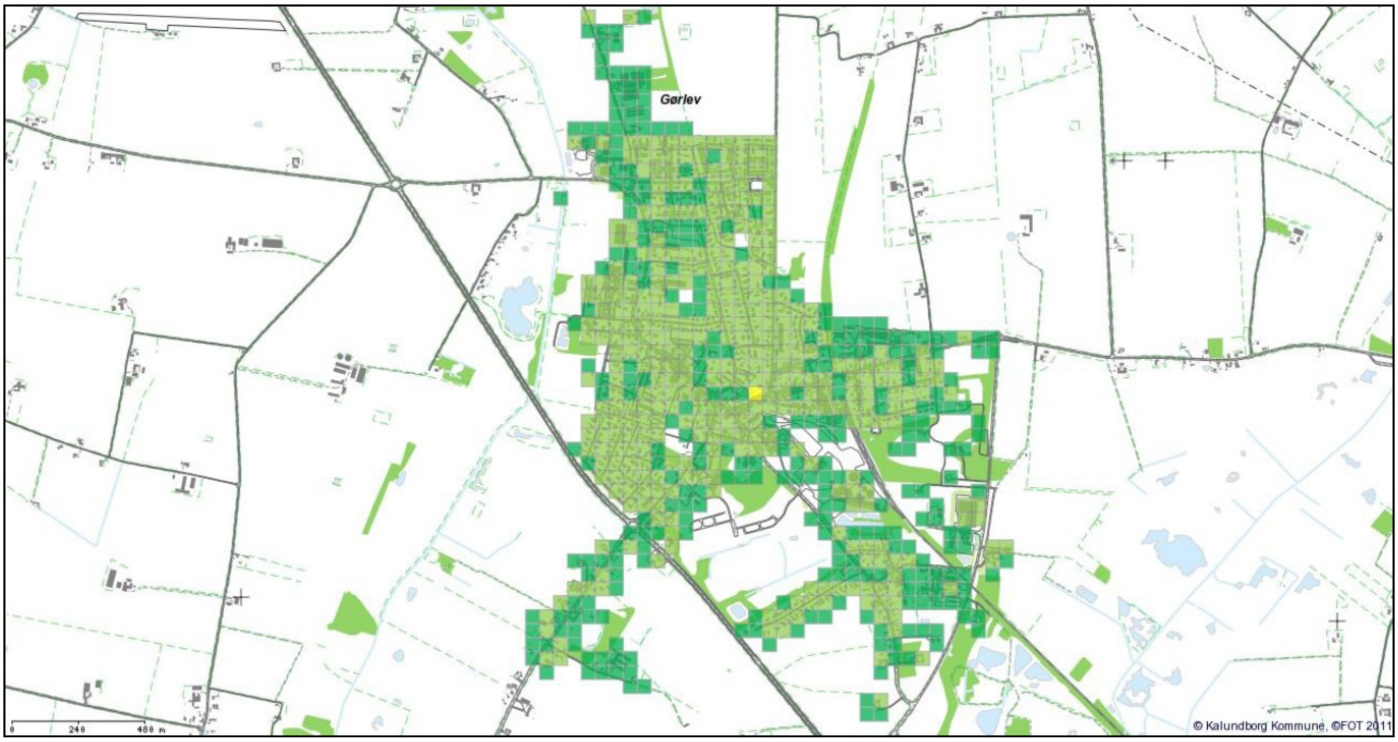



**Figure 6.11-1: Value map for Gørlev**

Notes: Dark green: values up to 2 m DKK; light green: values between 2 m DKK and 4 m DKK; yellow: values between 10 and 20 m DKK.

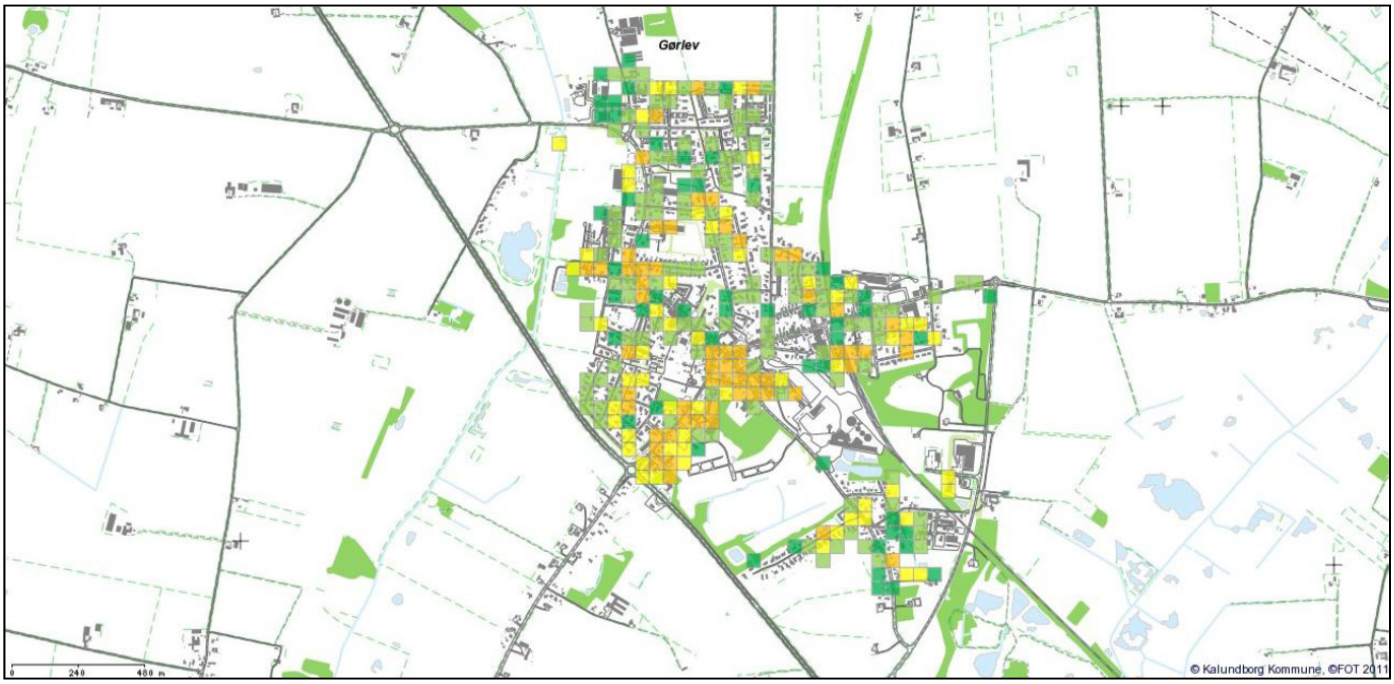



**Figure 6.11-2: Risk map for Gørlev**

Notes: Dark green: low risk; light green: medium low risk; orange: medium risk. Areas with no colour at not at risk of being flooded from the sewer system, to the minimum a 100-year rain event in 2050.

**Identifying effort areas**

The effort areas are identified based on the risk map linked to other plans and projects in the municipality and areas with special ¨value¨.

As previously discussed, the municipality choose to include only property prices in the economic valuation. Population density, for instance, has not been part of the valuation, which mean that an area with big private properties has been valued the same as densely populated areas with small houses even though flooding will affect a higher number of people.

Several places in the adaptation plan the "special values" of the municipality are highlighted. These are among others; nature protection areas, the cultural environment, preserve buildings, strategic infrastructure and important companies, technical installations and official buildings. Nevertheless, as the municipality choose to include only taxable value of property in the calculation of value maps, the special values did only have a minimum of impact on the selected "action areas". It should be observed here that for example important EU-preserved nature areas threatened by flooding has not been selected as "action areas" although it is mentioned in the adaptation plan that it should be assessed whether it is possibilities to place new areas with threatened tidal meadows further inland. Issues regarding which actions should be taken to protect preserved "nature against nature" seem to be a grey area in legislation.

## 6.12 Venice

Margaretha Breil, FEEM

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

**What is the climate change related problem/risk you would like to reduce by adaptation?**

Frequent flooding of ground floors of buildings in the historic centre of Venice determines a significantly higher level of building maintenance costs if compared to "normal" cities not interested by regular flooding by salt water. The "damages" caused by flooding in the building sector are thus defined as the major cost of maintenance due to flooding in the Venice lagoon, depending either on the number of inundation after which maintenance is required, or the distance to the water level in the ground which determines different frequencies of maintenance interventions for walls without protection.

Flooding already happens periodically, and with an increasing frequency due to local subsidence processes and will intensify in the future with increasing sea levels. Adaptation measures already put in place and considered in the CBA belong to the category of Flood proofing of existing buildings[56].

**Figure 6.12-1: Damages to brick walls from salt intrusion**

**Figure 6.12-2: Protection measure: barrier**

[56] Calculations are made so far only for residential units.

Figure 6.12-3: Protection measure barriers in walls

Figure 6.12-4: Protection measure: complete impermeabilization

The confrontation of damages will encompass several different states modelled:

- Damages caused in the actual state of buildings and the number and form of adaptation measures put in place and revealed by the survey,
- A state where all ground floor units are assumed to be protected with flood protection measures and
- Two different scenarios assuming (1) the generic application of smaller measures (at lower costs), and (2) the generic realization of the most costly measure which consists of the impermeabilization of the entire ground floor, including the static enforcement of the floor by a so called "vasca",
- A situation where no adaptation measures are put in place.

Results from the 5th IPCC Assessment report do not provide further detail with regards to specific prospective on sea level rise for the Mediterranean: "For 2081–2100 compared to 1986–2005, projected global mean sea level rises (meters) are in the range 0.29 to 0.55 for RCP2.6, 0.36 to 0.63 for RCP4.5, 0.37 to 0.64 for RCP6.0, and 0.48 to 0.82 for RCP8.5 (medium confidence; WGIII AR5 Chapter 5). There is a low confidence on projected regional changes (Slangen et al., 2012; WGI AR5 Section 13.6). Low-probability/high-impact estimates of extreme mean sea level rise projections derived from the SRES A1FI scenario for the Netherlands (Katsman et al., 2011) indicate that the mean sea level could rise globally between 0.55 and 1.15 m, and locally (Netherlands) by 0.40 to 1.05 m, by 2100. Extreme (very unlikely) scenarios for the UK vary from 0.9 to 1.9 m by 2100 (Lowe et al., 2009)." (Kovats, et al., 2014, p. 1276)

With regards to the Mediterranean, climate change scenarios foresee rises in temperature above global means (OECD, 2010) decreases in precipitation, and in some cases, decreases in winter storminess (Gualdi et al., 2012). Projections for future levels of eustatism for the Mediterranean are complex and not straightforward; as a series of dynamics (rate of evaporation, salinity, patterns of exchange in the straight of Gibilterra) contribute in different ways to the evolution of sea levels in the basin. Gualdi et al. (2012) estimate a rate of increase of 7 – 12 cm for 2050; or 13 cm for 2100 under an A2 scenario for the steric component; Vellinga et al. (n.d.) find for the period until 2100 changes in the range of -22 to 31cm of steric sea level rise, according on single model outputs for three different scenarios (Vellinga et al., n.d.). It has to be underlined that contributions due to the melting of ice sheets are not considered in any of these scenarios With regards to tendencies in storminess, climate models for the Mediterranean show, a possible tendency of decreased storminess, but it is not possible to deduct any tendencies in the conditions creating of extreme events in the northern Adriatic (seiches, strong south-eastern winds, and tidal excursion).

**Which adaptation tipping points can be identified?**

A key tipping point in the case of flood proofing of buildings and ground floor units is given by physical conditions of the building, especially the heights of ceilings of the indoor spaces: floor levels cannot be raised beyond a certain level without compromising indoor living quality.. With regards to cultural heritage, raising floor levels potentially creates conflicts with the conservation aims, whereas other techniques for safeguarding (insulation in a “vasca”/basin) will reduce accessibility. If flooding becomes more frequent or flood levels increase, usability of buildings will be limited. These tipping points might be crossed well after 2050.

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

**What are the alternative adaptation measures?**

The primary objective of adaptation measures is to reduce damages from flooding on private real estate assets in the historic centre of Venice. The secondary aim is to maintain the city as a living environment. At building levels, which is the one considered in this assessment, the measures aim at flood proofing existing buildings. New construction is quantitatively less important in the historic centre of Venice; those few cases of new buildings are generally realized with ground floor levels above the actual 1 in 100 years threshold for flooding, which corresponds to the level of flood reached in 1966, which is the highest level of flooding measured so far.

The measures for adapting existing buildings (flood proofing) consist of changes in building materials and techniques, aiming at protecting living environments from being flooded (raising floor levels, small barriers, protection of building elements against intrusion of salt water, with protective construction elements (vasca)) and preventing saline water from penetrating into brick walls by physical barriers introduced into walls.

In the public space, pavement levels have been raised as far as possible in order to improve pedestrian circulation during flood events. Costs of these interventions could not be quantified as the public agency does not release the data.

Both public and private strategies mainly refer to current risk levels, increasing flood levels/flood frequencies will lead to tipping points and/or require different flood protection measures.

**Table 6.12-1: Estimations of implemented adaptation measures**

| | Raising floor levels | Barriers | Pumps | Imper-meabilization | Cutting walls | Any measure* |
|---|---|---|---|---|---|---|
| **Residential units** | | | | | | |
| Sample | 783 | 310 | 62 | 85 | 182 | 1026 |
| All units (estimated) | 1.415 | 560 | 112 | 154 | 329 | 1.854 |
| % | 32 | 13 | 3 | 4 | 8 | 42 |
| **Commercial units** | | | | | | |
| Sample | 469 | 502 | 191 | 98 | 86 | 944 |
| All units (estimated) | 1.083 | 1.159 | 441 | 226 | 199 | 2.179 |
| % | 18 | 19 | 7 | 4 | 3 | 36 |

The baseline situation, defined by the state of the database available, is 2001, as for this year, both detailed information on indoor conditions and about adaptation measures implemented in ground floor units in the historic centre are available. Some adaptation measures have been implemented in approx. 36% of the cases; reducing or completely eliminating damages; in the remaining cases flooding occurs and causes damages (see Table 6.12-1).

Complementary measures for flood protection consist of the establishment of a sophisticated early warning system managed by the local authority’s flood forecasting centre. It provides timely (at least 4 hours in advance, if possible some days in advance) alerts to the population via internet, text messages, answering machines, call managers and apps for smartphones, and, four hours in advance, a system of alerting sirens which provide information on the maximum flood level expected.

In case of flooding, up to a threshold level of 120 cm above local mean sea level, a system of public walkways is organized ensuring access to important places within the city, especially public boat stops.


**Figure 6.12-5: Map of connections (green) and walkways (red) up to 120cm**
Source: Comune di Venezia (2013)

In a pathway perspective, the measures of adaptation of the public space can be seen as part of a two-steps approach where up to "minor" flood levels these local measures will contribute the damages of flooding that continue occurring, whereas higher flood levels, (the actual discussion points to a threshold of 110cm) should be completely eliminated by the activation of the flood protection barriers actually under construction in the three lagoon inlets (Mose Project).

**What are alternative adaptation pathways?**

The official "sell by" date of the public flood protection measure is a sea level rise superior to 60 cm[57]. For individual flood proofing sell by dates are dictated by the possibility of raising floor levels and/or protection barriers without compromising possibilities of access and minimum standards for room heights. Sell by dates are thus determined by specific characteristics of the buildings which are difficult to identify under this strategy, as some units, situated at a lower level, will reach this tipping point sooner than others.

[57] https://www.mosevenezia.eu/?page_id=16&lang=en accessed on Sept. 18th, 2014.

**Step 3 - Evaluation Criteria and Method**

**Step 3a Selection of evaluation criteria**

**Which evaluation criteria should be used?**

The case study focuses on the costs and benefits of private measures put in place, as far as economic factors (damages in terms of increasing costs of maintenance, and investment costs (costs for flood proofing measures) are concerned. Investment costs are principally borne by private homeowners, but public finance subsidies were available for private intervention in restoration of buildings. The last assignment of funding was made in 2009. Funding was not specific for the implementation of protection measures, but for restoration work which could also include the realization of protection measures.

With regards to the public adaptation measures, a cost effectiveness assessment would have been suitable if alternative options were assessed. During an attempt of revising the state policy with respect to the protection project, the existence of alternative projects with considerably lower costs was highlighted (Città di Venezia, 2005), but the assessment procedure did not lead to changes in the project realization.

With regards to public flood proofing measures, benefits can be assessed in only in terms of qualitative improvements, costs are transparent only in part.

**Step 3b Selection of evaluation method(s)**

**What is the appropriate evaluation method?**

The economic analysis focuses on private investments in flood -proofing measures of buildings in the historic centre of Venice, applying a Cost Benefit approach to the assessment of investment costs and avoided damages. The assessment is based on the assumption that maintenance cost for buildings in Venice are higher because of flooding and the exposure of buildings to salt water in the ground and the fact that maintenance cost vary in relation to the frequency of inundation and the distance to the water level in the ground. Costs considered are based on the expenditure for specific measures that are realized for the protection of essential structures against saltwater intrusion and direct flooding of buildings. Benefits are calculated in terms of reduced costs of expenditure on building maintenance, based on average frequencies of maintenance intervention, compared to cities not affected by high water.

Public measures of adaptation and flood proofing (raising public floor space, walkways) will not be quantified but assessed on a qualitative basis, as costs are not being revealed by the public agency in charge of the works and benefits (being able to walk to all parts of the city) can be assessed only in a qualitative manner.

**Step 4 - Data collection**

**What are the costs and what are the benefits of the alternative adaptation options?**

The database used for the assessment of damages on ground floor units has been connected to a GIS of the historic centre of Venice, and information on levels of public pavements, which is important for defining the frequency of flooding for the single buildings has been inserted in the map.

Data on annual flood frequencies registered from 1966 until 2013 has been obtained the municipal centre for flood forecasting. These annual frequencies are detailed for levels in steps of 10cm, measured with reference to the local tidal reference point.

The cost estimate is based on the information extracted from the data- base created by the municipal authorities which contains a detailed description of the ground floor unites in the city. The database used for this analysis consists of a selection of data extracted from a database in 2001 the City of Venice, which registers more than 25.0000 building units, including doorways, courtyards, entrance halls, etc. (see Table 6.12-2).

**Table 6.12-2: Description of sample**

| | Data base | Sample | Share (%) |
|---|---|---|---|
| Residential use | 3,140 | 2,425 | 77,20 |
| Commercial use | 4,709 | 2,598 | 55,17 |
| Total number of units surveyed | 7,849 | 5,023 | 64,00 |

The construction of the sample is essentially driven by the criteria of availability of sufficient detail of data. For the purposes of this investigation information on those ground floor units registered as "residence" and commercial activities have been extracted for which detailed measurements were available.

In this way two sample databases were created, one containing the information on residential units and one with information on commercial units. The database created consists of a total of 2,598 observations regarding commercial use, which correspond to 55% of commercial units surveyed, and 2,425 or 77% of residential units surveyed in the database. For all units in the sample information is available for the kind of activities, as well as on physical parameters such as size, material, condition and on the intensity with which the unit is interested by flooding, measured in terms of floor level with respect to the local tidal reference point.

Costs of intervention for maintenance and information on frequency according to the frequency of flooding for each building element have been collected from expert judgement in a previous research in terms of difference between normal frequencies of maintenance works and frequencies caused by periodic contacts of building elements with salt water ( cite vector). Also the costs of adaptation measures have been elicited in the same manner.

In this way two sample databases were created, one containing the information on residential units and one with information on commercial units. The database created consists of a total of 2,598 observations regarding commercial use, which correspond to 55% of commercial units surveyed, and 2,425 or 77% of residential units surveyed in the database. For all units in the sample information is available for the kind of activities, as well as on physical parameters such as size, material, condition and on the intensity with which the unit is interested by flooding, measured in terms of floor level with respect to the local tidal reference point.

The economic values of costs or damages are calculated using specific depth-damage functions for single building elements (pavements, walls, doors). These functions assess annual increases in maintenance costs based on information on the location of the unit with respect to the medium sea level, the technical characteristics (plastered or non plastered walls, dimensions, number of doors, etc.) and the availability of protection measures. The aggregate value of these estimates is based on detailed information on a relevant part of the ground floor units which have been revealed from inside.

Damages on buildings in the historic centre of Venice are caused by contact with salt water, which deteriorates bricks, plasters and doors. With regards to pavements, expert opinion indicates that, if properly maintained/rinsed with freshwater, any traditional material used for floors (marble, venetian floors, etc.) is not damaged, so for floors, only costs for cleaning with freshwater after each inundation are considered as maintenance costs.

Data on conditions of ground floor units dates back from 2001 from a comprehensive survey organized by the local authority. 2001 will thus need to be assumed as a baseline situation, for which the entity of existing protection measures and the technical characteristics have been recorded in the database.

**What is the evaluation time frame?**

The actual lifespan of adaptation measures, which should be assumed being similar to those of buildings (approx. 50 years), has been chosen as timeframe. Thus, as an initial time reference the time when the state of investments has been surveyed (2001), thus the end of the time frame has been set at 2050. A longer time frame would come with stronger assumptions, as it is to be expected, that types of uses will change with changing conditions of flooding, and the city will adapt (as far as possible) transferring more sensitive uses like residences into higher floor levels and into higher areas within the city.

**Which discount rate should be applied?**

There are no rules for the application of discount rates in Italy, so only a sensitivity analysis will be used exploring results from the application of a lower (1%), a medium (3%) and an upper bound (5%) of the discount rate.

**How to deal with data uncertainty?**

Treating with a retrospective case, uncertainties are limited to variations between actual and average conditions. The cost assessment is based on expert knowledge; uncertainties related to the accuracy of this information are tackled indicating minimum and maximum values corresponding to lower and upper bounds of estimates.

**Step 5 – Evaluation and Prioritization**

**What is the ranking order of alternative adaptation options (measures, bundles of measures or pathways)?**

**Table 6.12-3: Net present values for costs and benefits for Residences at present state of adaptation (2001-2050)**

| Discount rate | 1% | 3% | 5% |
|---|---|---|---|
| **No SLR** | | | |
| Costs (NPV) 36.437.376 | | | |
| Benefits (NPV) | 10.158.065 | 6.800.167 | 4.918.580 |
| Damages (NPV) | 163.517.205 | 109.464.188 | 79.175.750 |
| | | | |
| **SLR +10 cm** | | | |
| Costs (NPV) 36.437.376 | | | |
| Benefits (NPV) | 10.172.303 | 6.814.405 | 4.932.817 |
| Damages (NPV) | 164.841.131 | 110.788.113 | 80.499.675 |
| | | | |
| **SLR +30 cm** | | | |
| Costs (NPV) 36.437.376 | | | |
| Benefits (NPV) | 10.382.814 | 7.024.916 | 5.143.328 |
| Damages (NPV) | 166.091.558 | 112.038.540 | 81.750.102 |

The results from modelling of the present state of adaptation show that costs for adaptation measures actually adopted (at 2001 values) largely exceeds the net present values of benefits to be expected over the period from 2001 to 2050 and are significantly lower than expected damages, both at present sea levels and under scenarios of sea level rise.

This apparent lack of correspondence between costs and benefits (measured in this case in terms of reduced maintenance costs for private buildings) might find explanations in dimensions which are difficult to be assessed in monetary terms, nevertheless are part of individual criteria for decisions on investments. Further to the economic benefits related to maintenance costs of buildings, mostly immaterial benefits need to be considered in relation to periodic inundation o residential and commercial units. First of all, these regard psychic stress related to having (parts) of the personal living space inundated; furthermore, time is required for undertaking the specific arrangements to protect mobile assets (household appliances etc.) which need to be taken in time. The early warning system put in place by the public authority is used for this scope, as it allows both residents and owners of commercial activities to prepare their units removing, as far as possible, sensitive objects from areas that can be reached by water[58]. Furthermore non monetary benefits comprise option values corresponding to the value attributed to the time needed for preparing the unit before a flood and of cleaning up (essentially rinsing floors with fresh water) after the end of the inundation. Actually only the economic value of the working time needed has been

[58] It must be noted that insurances do not provide coverage for flood damage; the attempt of estimating potential losses of mobile assets is thus extremely complicated because of the lack of available data.

included in the assessment, but not the value attributed to foregone activities planned for the time actually needed for cleaning up.

**Table 6.12-4: Net present values for costs and benefits for private residences under the scenario of full impermeabilization (2001-2050)**

| Discount rate | | 1% | 3% | 5% |
|---|---|---|---|---|
| **No SLR** | | | | |
| Costs (NPV) | 351.684.738 | | | |
| Benefits (NPV) | | 107.812.419 | 72.173.438 | 52.203.247 |
| Damages (NPV) | | 65.862.851 | 44.090.917 | 31.891.082 |
| **SLR +10 cm** | | | | |
| Costs (NPV) | 351.684.738 | | | |
| Benefits (NPV) | | 108.594.451 | 72.955.470 | 52.985.279 |
| Damages (NPV) | | 66.418.982 | 44.647.048 | 32.447.213 |
| **SLR +30 cm** | | | | |
| Costs (NPV) | 351.684.738 | | | |
| Benefits (NPV) | | 109.206.965 | 73.567.984 | 53.597.793 |
| Damages (NPV) | | 67.267.406 | 45.495.472 | 33.295.637 |

With regards to commercial units, further to the material losses, the economic losses due to the interruption of economic activities needs to be taken into account, although not entirely to be attributed to the inundation of the unit itself, but also due to problems in reaching the unit because of flooding of the public space. In 2002 an attempt of quantifying losses by commercial units used scenarios in which continuous low level flooding and single high level events could be avoided, yielding a present value between 1 and 1.7 Bn EUR considering loss of activity, merchandise and time for rearranging and clearing up (Sgobbi, 2003, internal report).

The actual discrepancy between benefits and damages is based largely on the fact that actually only a relatively small number of units is protected by measures. Thus the value of investment in private adaptation measures refers to a relatively small number of interventions.

The decision of not adopting protection measures can be seen on the one side, in the relatively low level of economic benefits of the measures produce for the individual investor. On the other hand side, public investment in the early warning system and the private experiences with flooding events have created some routine, which facilitates dealing with inundations and preventing additional damages.

Assuming that private actors decide on their investments in an economically rationale manner, the fact that actually relatively few investments in protection measures have been made, can be sought in the individual judgement that the total of monetary and non-monetary benefits that can be obtained from the investment does not equal the costs, or perhaps in the lack of private resources for the necessary investments.

Also considering the relation between investment costs and net present values of expected benefits under a hypothesis of the most expensive and comprehensive protection measure (*vasca*) adopted in all units, still a substantial disproportion is visible, with investment costs exceeding calculated benefits by more than three times. This holds even under a scenario of substantial sea level rise (+ 30 cm until 2050 with a consequent increase of level and frequencies of inundations). Under this scenario with a maximum range of protection measures in place, still some residual damages must be expected, although at a significantly lower rate.

The Scenario simulation based on the assumption of small measures (punctual insulation measures like barriers and pumps, etc. offers a slightly better relationship between investment costs and benefits), although costs from damages remain consistent.

**Table 6.12-5: Net present values for costs and benefits for residences under the scenario small adaptation measures (2001-2050)**

| Discount rate | | 1% | 3% | 5% |
|---|---|---|---|---|
| **No SLR** | | | | |
| Costs (NPV) | 39.967.298 | | | |
| Benefits (NPV) | | 62.149.435 | 41.605.025 | 30.093.030 |
| Damages (NPV) | | 111.525.836 | 74.659.330 | 54.001.300 |
| **SLR +10 cm** | | | | |
| Costs (NPV) | 39.967.298 | | | |
| Benefits (NPV) | | 62.445.346 | 41.900.936 | 30.388.941 |
| Damages (NPV) | | 112.568.087 | 75.701.581 | 55.043.551 |
| **SLR +30 cm** | | | | |
| Costs (NPV) | 39.967.298 | | | |
| Benefits (NPV) | | 62.702.910 | 42.158.500 | 30.646.505 |
| Damages (NPV) | | 113.771.461 | 76.904.956 | 56.246.925 |

A third scenario simulating the adoption of the actually most diffuse protection measure which consists of raising floor levels inside the unit yields very low benefits in terms of avoided maintenance costs, as it does not protect walls from salt water intrusion. Nevertheless, it avoids the inside of the unit being flooded, protecting thus, further to inner doors and the floors themselves, household appliances, furniture etc. which have not been considered in this assessment as these can easily be protected by specific arrangements to be taken in the moment of flood warnings.

**Table 6.12-6: Net present values for costs and benefits for Residences under the scenario of only floor level raising (2001-2050)**

| Discount rate | | 1% | 3% | 5% |
|---|---|---|---|---|
| **No SLR** | | | | |
| Costs (NPV) | 80.186.830 | | | |
| Benefits (NPV) | | 17.539.564 | 11.741.603 | 8.492.734 |
| Damages (NPV) | | 156.135.707 | 104.522.752 | 75.601.596 |
| **SLR +10 cm** | | | | |
| Costs (NPV) | 80.186.830 | | | |
| Benefits (NPV) | | 17.350.264 | 11.552.303 | 8.303.434 |
| Damages (NPV) | | 157.663.169 | 106.050.214 | 77.129.058 |
| **SLR +30 cm** | | | | |
| Costs (NPV) | 80.186.830 | | | |
| Benefits (NPV) | | 17.455.617 | 11.657.656 | 8.408.787 |
| Damages (NPV) | | 159.018.755 | 107.405.800 | 78.484.643 |

## What are the main lessons learnt from your case study?

As a conclusion of the results of these simulations and taking into account that damages resulting from the flooding of public spaces in terms of difficulties in movements, it can be concluded that private flood adaptation measures for buildings can considerably reduce damages, but are not able to avoid them totally; especially with regards to non-monetary damages. Private adaptation comes, furthermore under most of the options with a considerable level of investment costs, which may not be affordable for all households. The fact that some measures are employed despite a low cost-benefit rate, furthermore points to the fact that values not taken into consideration, especially the damages and losses in life quality and stress play an important role in private decisions.

## 6.13 Alentejo

Inês Campos, André Vizinho and Filipe Moreira Alves, FFCUL

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

The projected impacts from climate change for the Mediterranean region are well known and documented. In fact, the Mediterranean dry lands have been identified as one of the most prominent regions affected in climate change projections (Schröter et al. 2005, Giorgi 2006). Temperature rise – larger than any other European region -, increase in heat waves, together with a decrease in precipitation envision a future of increased risk of desertification and biodiversity loss for most of southern Portugal, Spain, Italy and Greece (EEA 03/2013). In the Portuguese history, drought[59] events occur often with severe consequences, namely in agriculture production. In the last 65 years Portugal witnessed seven extreme drought periods: 1943/46, 1965, 1976, 1980/81, 1991/92, 1994/95 e 1998/99 e 2004/06. From these, the 2004-06 was by far the one with the biggest territorial cover (100% of the Portuguese national territory) and the most intense in duration and severity (see Figure 6.13-2) as well as overall cost, estimated in 286.205.800 EUR (PNUEA Report, 2012). These estimated costs, however, do not enclose all assumed social, economic and environmental costs – for example the rise in $CO_2$ Emissions and consequent economic costs – as droughts can have multi-sectorial and multi-scale impacts (Figure 6.13-2). This is particular relevant for the Alentejo region where agriculture productivity has a strong relation with the region's income and droughts can have a significant impact in people migratory dynamics and in the human and environmental desertification[60] of this region. It is also important to acknowledge that in such regions such as the Alentejo droughts can play an even more crucial role in intensifying the cycle of desertification (Figure 6.13-5) as these are already fragile ecosystems with high social and environmental exposure to droughts (PNCAD, 2004).

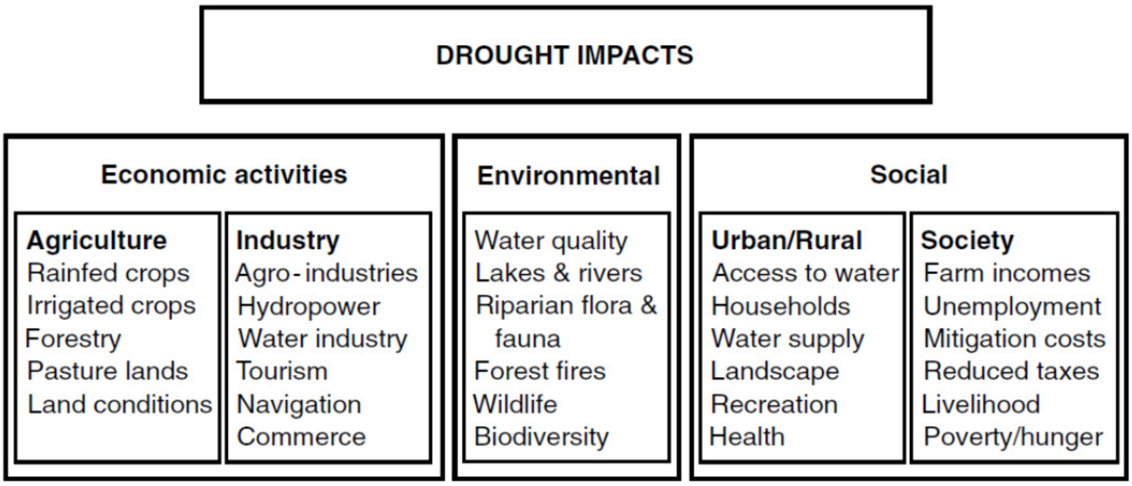



**Figure 6.13-1: Drought impacts**
Source: Pereira et al 2010

[59] In this report we consider Drought's to be temporary natural water scarcity conditions derived from climatic conditions. According to Pereira et al (2010), „..drought is defined as a natural but temporary imbalance of uncertain frequency, duration and severity, whose occurrence is difficult to predict".

[60] According to the UNCCD Desertification is „land degradation in arid, semi-arid and dry sub-humid regions resulting from various factors, including climatic variations and human activities."

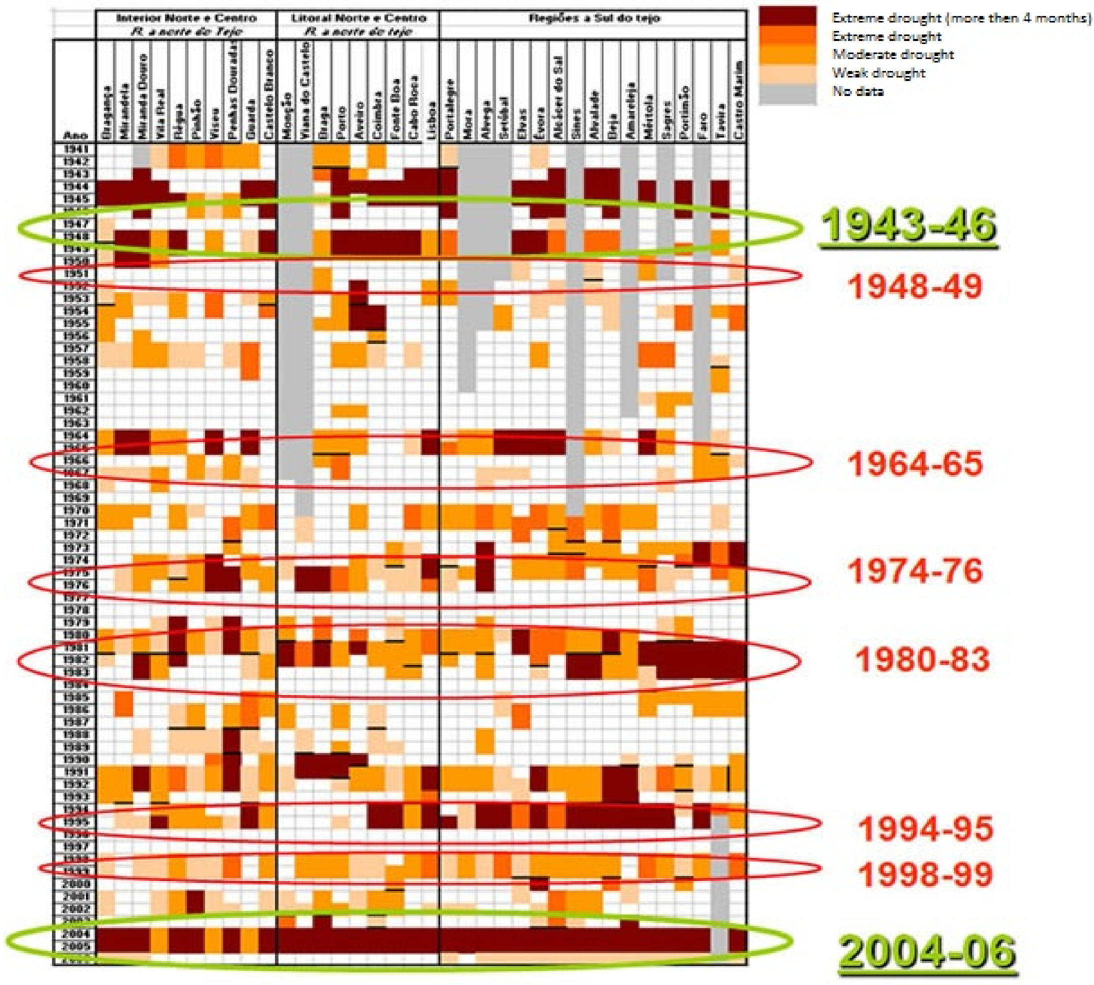



**Figure 6.13-2: Territorial cover and severity of droughts in Portugal in the period 1941-2007**

Regarding the monitoring and measuring of droughts, the Palmer Drought Severity Index (PDSI)[61] has been calculated from 1900-2014 for Portugal with relevant conclusions, namely the fact that in the last decades we've observed an intensification in the frequency of droughts, particularly in the months from February to April (see figure 7, Pires et al 2010) and in the Alentejo region (see figure 6 below for the city of Elvas). More recently and after the December 2009 Lincoln Declaration on Droughts Indices, signed by consensus by the UNCCD, the Portuguese national meteorological institute is also using the Standard Precipitation Index (SPI)[62] which yields similar results and overall conclusions.

Both of the fore mentioned indices only produce historical data based on observations and modelling and do not offer future predictions for these extreme weather events. However, the European Centre for Medium-Range Weather Forecasts (ECMWF) does provide EU members with a medium-range (30 and 90 days) forecast for the PDSI, which can be used to develop better early warning systems.

[61] The PDSI is just one of many possible indicators to measure drought. It is considered as an metereological index. However, some authors also refer to its relevance for agriculture as the main purpose is to measure the departure of the moisture supply in the soil. For more information on the PDSI please see Palmer WC (1965), Metereological drought, Research paper No. 45, US Dept. Of Commerce

[62] For more information and comparison between the two indices please see Guttman, N.B. (1998), Comparing the Palmer Drought Index and Standardized Precipitation Index, Water Resources Association, No. 34, pp: 113-121

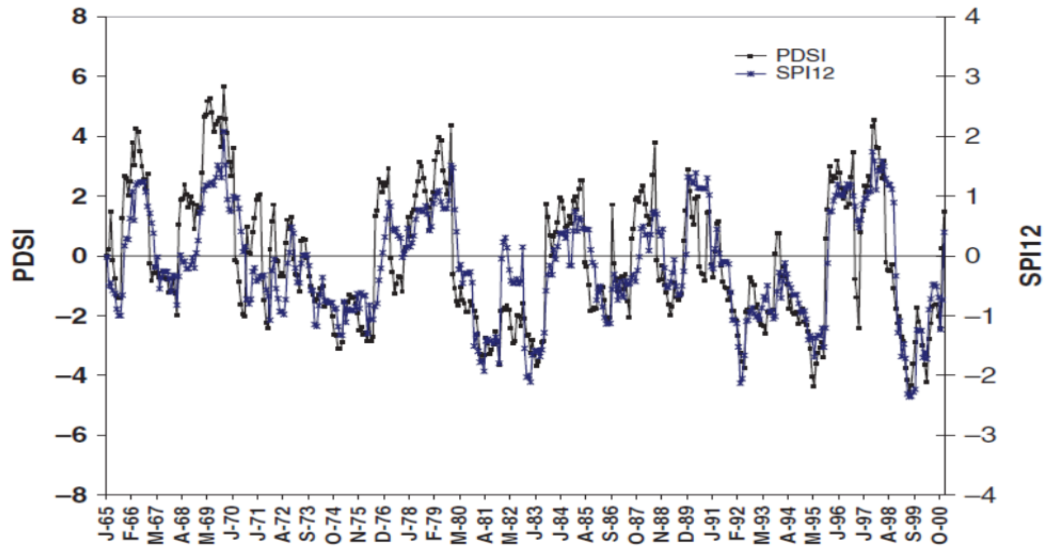



**Figure 6.13-3: Comparing the drought indices PDSI and the 12-month SPI[63] 1965-2000 for Elvas, Portugal**
Source: Pereira et al (2010)

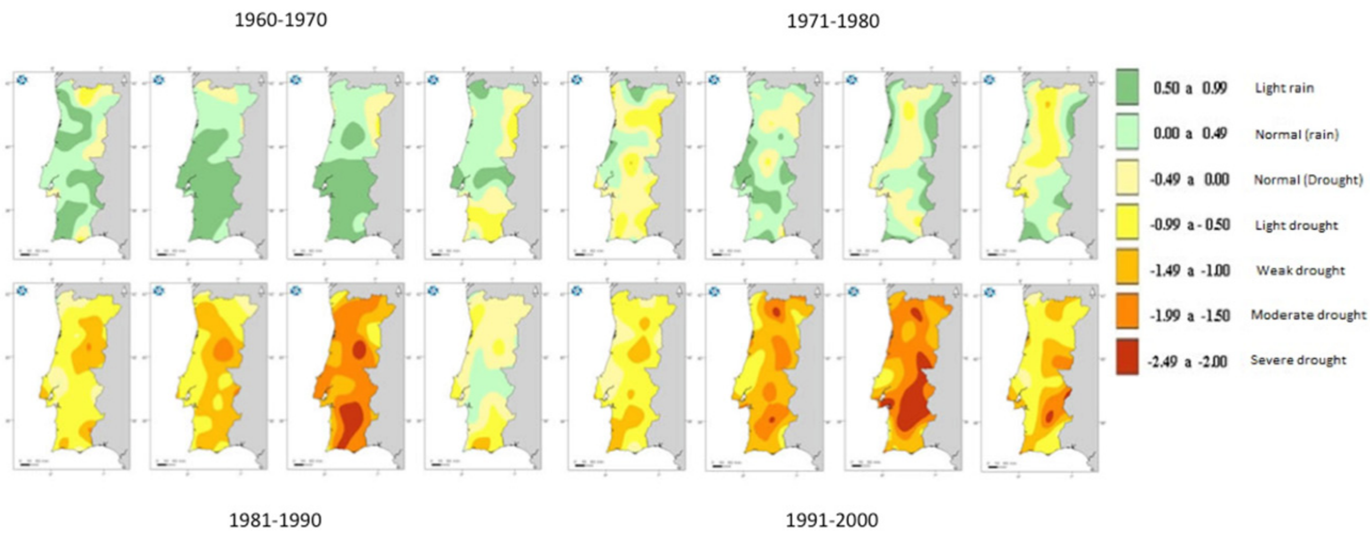



**Figure 6.13-4: Historic evolution of the PDSI 1961-2000 in Portugal (Trimestral average)**

[63] SPI: Standard Precipitation Index

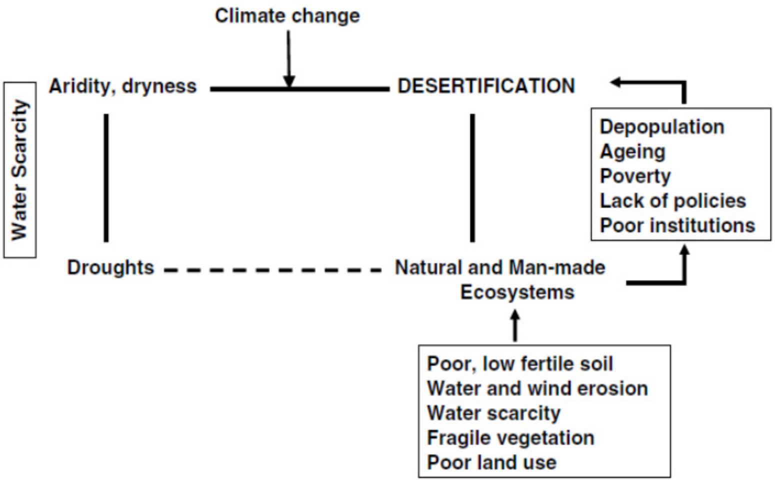



**Figure 6.13-5: The circle of the desertification integral process**
Source: Pereira et al (2006)

The IPCC WGII AR5 reports that analysing and predicting future trends in droughts occurrence due to climate change is a complex processes with inherent difficulties not only regarding the categories and definitions of drought (meteorological, hydrological, etc.) but also regarding the lack of observational data and the unpredictability of extreme weather events. Nevertheless, the Mediterranean region shows a clear trend towards more severe (Wong et al. 2011), more frequent (Hisdal et al. 2001, Iglesias et al. 2007) and longer droughts (Kim and Byun 2009), with increased water stress due to precipitation decline (Collins et al. 2013; Hesselbjerg et al. 2013; De Luis et al. 2001, De Dios 2007) and decreased groundwater recharge (Boko 2007).

Even taking into consideration multiple models under RCP 4.5 the impacts felt on the Mediterranean are among the most severe worldwide concerning droughts (Figure 6.13-6). This is also the case for mega-drought events[64], for which there is a growing risk projected for the Mediterranean region in all RCP scenarios.

Finally, it is crucial to highlight that these projected drought events can strongly exacerbate soil erosion, loss of top soil and nutrients flow and availability, which is directly connected with the capability of ecosystems deliver key services, such as water purification (De Groot et al. 2010, Keller et al 2012), and these with agriculture productivity and human habitability of such regions (Rosenzweig and Tubiello 1997). The cycle of desertification identified (Figure 6.13-5) is also strongly influenced by future projections of increase in water demand (EEA 12/202) and other pressures in ecosystems such as higher urbanization pressures.

[64] Mega-droughts or multi-decadal droughts are decades-long droughts lasting two decades or more (Cook et al. 2011). The term has been used in grey literature also to describe multiyear droughts with strong severity, such as the Dust Bowl drought 1930's.

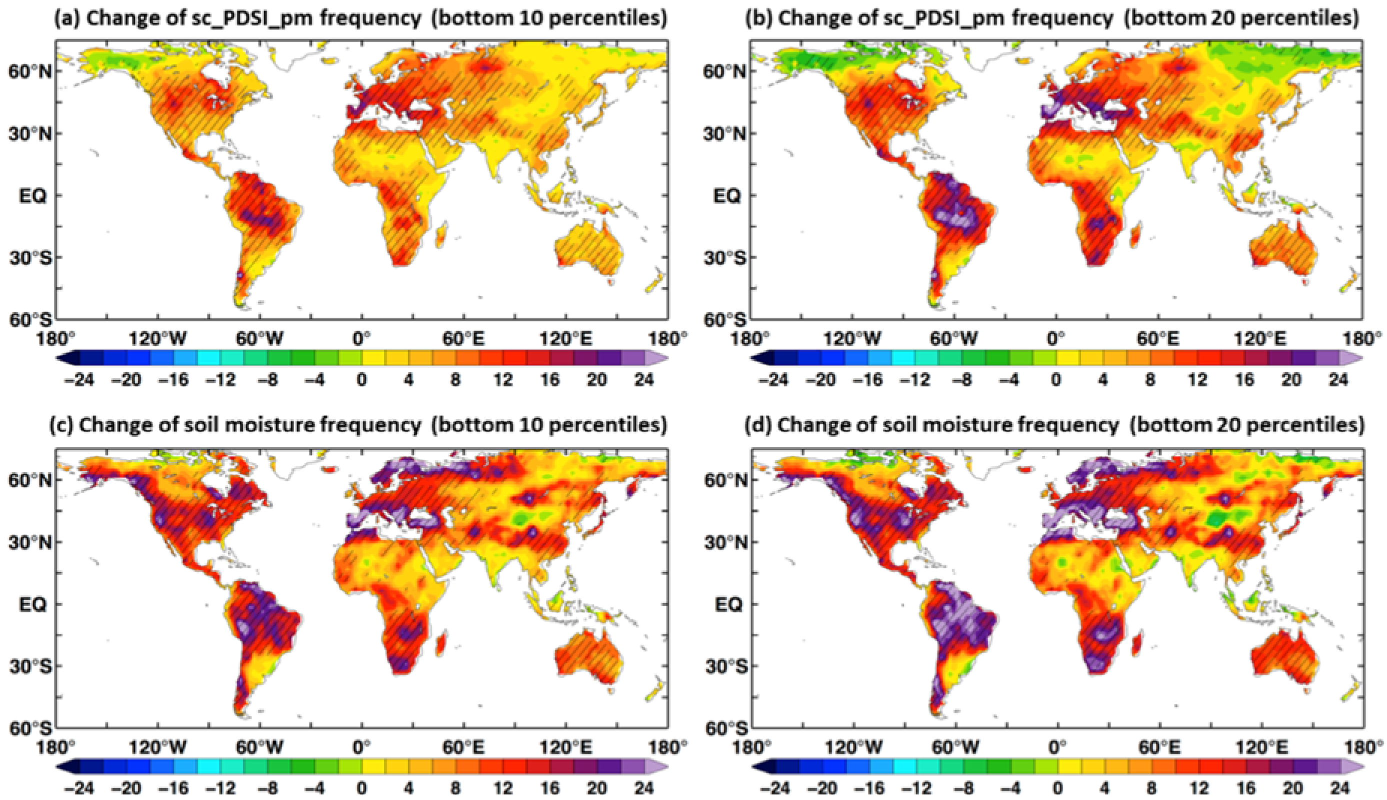



**Figure 6.13-6: Multi-model ensemble averaged changes of drought frequency from 1970-1999 to 2070-2099 under the RCP 4.5 scenario**
Source: Zhao, Dai (2014)

**Step 2 – Identification of Adaptation Measures**

Within the existing national strategies already mentioned (PNCAD, ENAAC, PNUEA) several mitigation and adaptation measures to face climate change impacts in the Alentejo have been identified, analysed and ranked. During BASE, regional stakeholders - practitioners (Farmers), farmers associations, decision-makers and researchers - were convened in a participatory workshop in order to discuss and vote for Alentejo's most effective and efficient measures to deal with climate change future impacts. In this event (November 2014), 21 adaptation measures to face drought and water scarcity were considered and voted regarding Droughts and Water Scarcity. Among mulching and other soil coverage techniques, crop diversification, holistic management together with new irrigation systems, there is a group of measures that concerns rainwater harvest and retention but that differ significantly in terms of scale and uses. From the construction of big dams used to irrigate vast areas to the management of small-scale seasonal ponds, different options with different impacts were considered. Among them, the Water Retention Landscape (WRL) of Tamera (see Figure 6.13-7 and Figure 6.13-8) stands out as a unique case study not only due to its Permaculture[65] holistic design but also due to the larger vision it represents: A Vision for a 1000 lakes in the Alentejo.

[65] Permaculture is and holistic design system based on ethics and principles derived from the observation of nature's patterns and which can be applied to the development of environmental, economic and social systems that support sustainable livelyhoods (Homgren 2004).

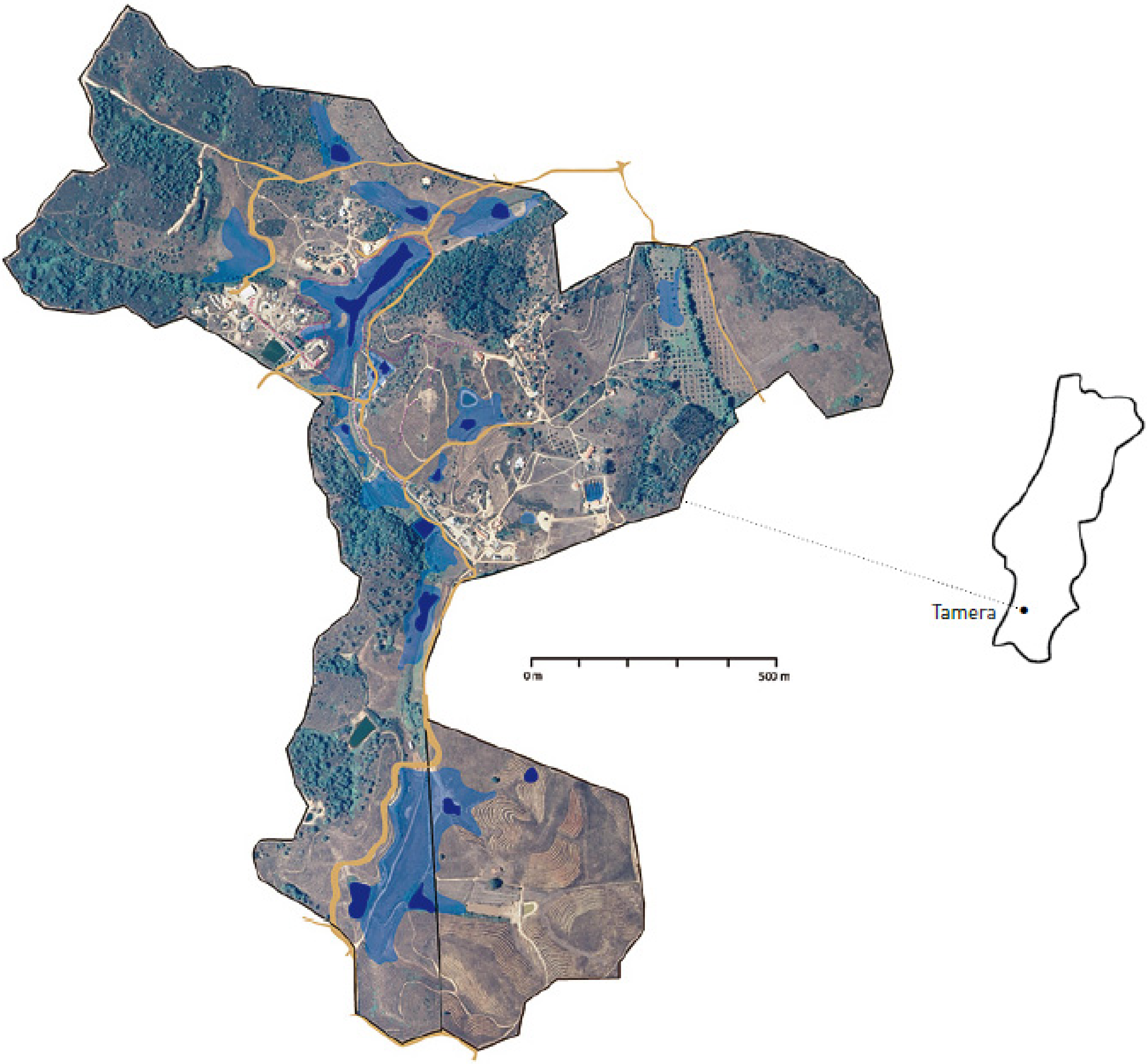



**Figure 6.13-7: Water Retention Landscape of Tamera in 2013**

According to CIRCLE-2 publication “Adaptation Inspiration Book” (2013)[66], water retention landscapes (WRL): “are permanent artificial lakes that serve to manage storm water runoff, prevent flooding and erosion, improve the water quality and support the restoration of the water cycle by retaining the water in the areas where it falls as rain. In addition, they improve the quality of their environment and allow for groundwater recharge. Water retention basins are sometimes also referred to as wet ponds. A water retention landscape consists of a series of interconnected retention spaces, from pond-sized up to lake-sized, in which the rainwater can collect behind a dam constructed from natural material. The retention spaces themselves are not sealed with concrete or any artificial layer, so the water can slowly but steadily diffuse into the earth-body.” It is important to highlight that rainwater harvesting has been neglected in recent agricultural water supply developments, even though there is a long history in traditional water supply for agricultural purposes (Wisser et al 2010; Frolking et al. 2010). Especially the significance of rainwater harvesting in small reservoirs has been underlined by several studies in semi-arid zones (Smith et al. 2002; Van de Giesen et al. 2005). Water storage in soils of the Alentejo region seems to be rather low, as soils of the

[66] Available for download here: http://www.circle-era.eu/np4/552.html

region, derived from schist or granite, are mainly characterized by scarcity in organic matter, thinness and low water storage capacity (Correia 1993). Additionally, soil erosion as a result of deforestation, agricultural mechanization and often very strong rainfall events, contributes to low water absorption by soils of the region.

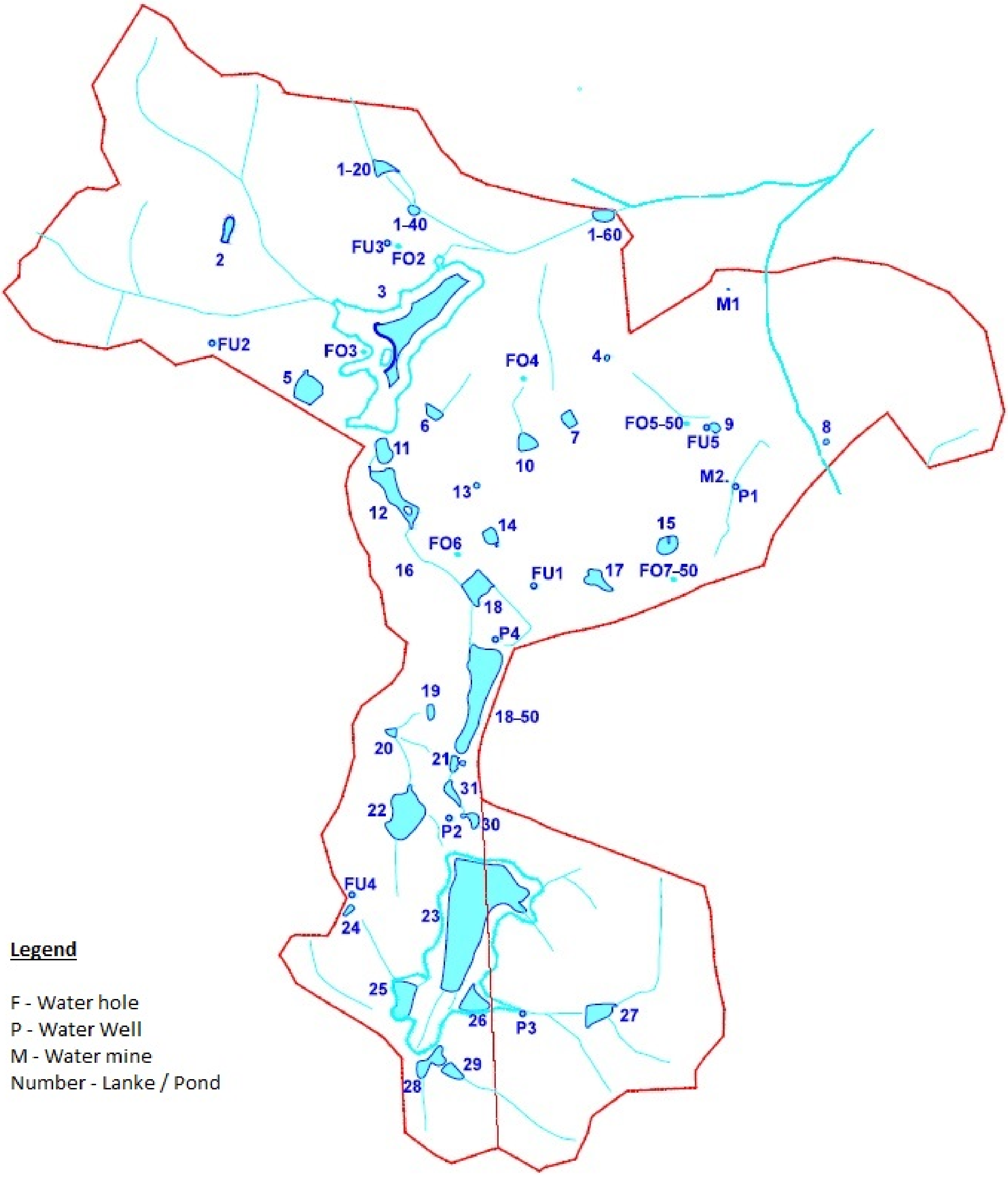



**Figure 6.13-8: Tamera's water sources 2015**

The WRL of the Tamera ecovillage, designed in collaboration with Permaculture expert Sepp Holzer, has been in construction since 2005 following more than 20 years of community living in a 155ha property near Colos, Odemira. Tamera's has had and still has multiple water sources – Water mines, holes, well's, ponds and lakes – in order to support the livelihood of the resident community (Figure 6.13-8). These are crucial elements in the shaping of the landscape as well as in the shaping of the community itself and the activities developed, namely agriculture. The land cover in 2006 and in 2014 is shown in Figure 12. The changes observed reflect the construction of several artificial lakes, making the area of water bodies to increase from 0,62ha in 2006 to 8,32ha in 2014 (Figure 6.13-7 and Figure 6.13-8). The lake construction and the increase of water availability allowed the development of arable land. Transitional woodlands increased from 9,34ha to 19,50ha mainly in the southern area. Natural grasslands is the only land use and land cover category which decreased between 2006 and 2014, from 62,89ha to 35,84ha, since the construction of the artificial lakes and the associated expansion of arable land, as well as the development of transitional woodlands took place mainly in areas previously occupied by natural grasslands. The area occupied by broad leaf forest remained approximately the same (63,89ha in 2006 to 64,29ha in 2014), and no changes were observed regarding the areas of discontinuous urban fabric and olive groves between the analysed time-span.

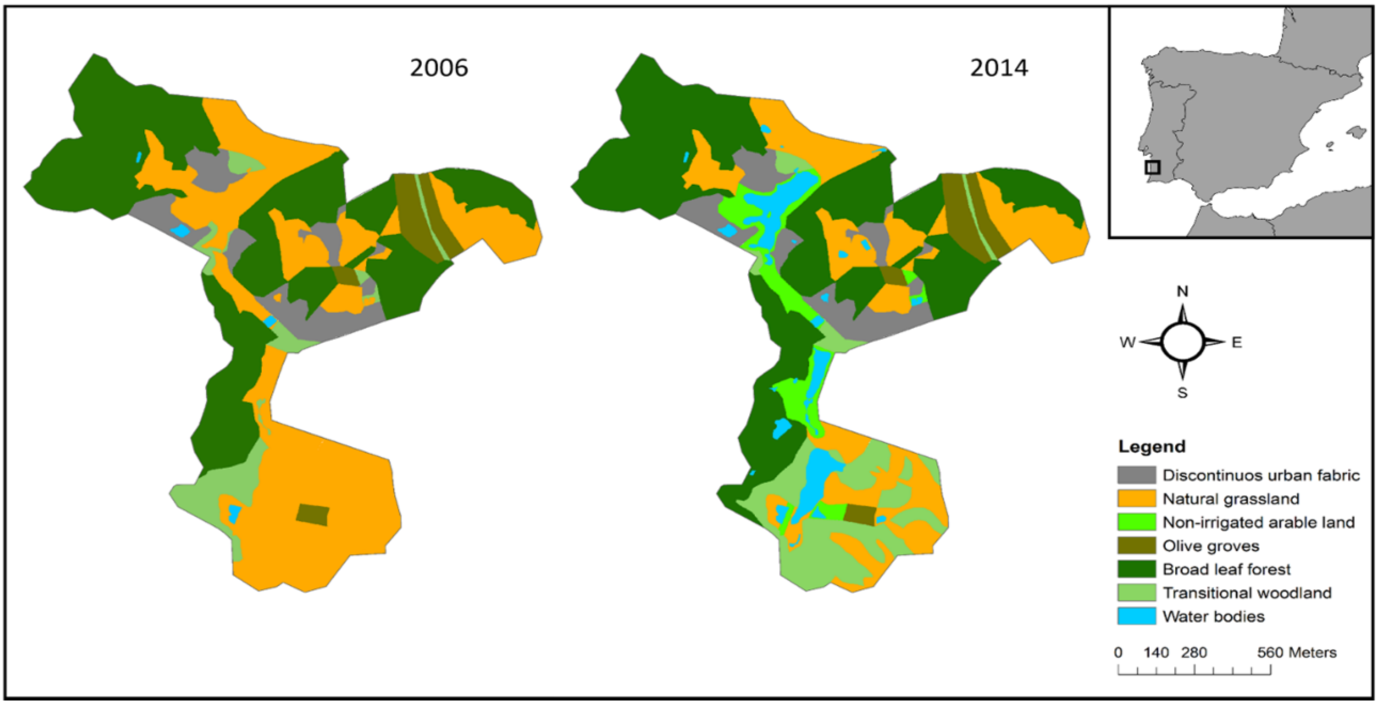



**Figure 6.13-9: Past (2006) and current (2014) land cover for the study area and its location in the south of Portugal**
Source: Santos et al (2015)

**Step 3 - Evaluation Criteria and Method**

Due to the intrinsic complexity of such an investment as well as due to the holistic dimension of the WRL in the specific case of Tamera the choice of the evaluation criteria, it's proxy's and appropriate weighting were identified in close partnership between scientific experts and members of the community of Tamera in two separate moments. In an initial research moment, scientific experts convened with Tamera's representatives Christopher Ulbig and Fátima Teixeira to co-identify and validate indicators and criteria's for the economic assessment; in a second moment a participatory benefit-cost analysis was performed with 30 community members, who reached consensus decision regarding the key positive and negative impacts to be valued and accounted for in any economic analysis.

The key benefits initially identified were:

**Table 6.13-1: Main benefits identified by BASE Team together with Tamera representatives**

| | Benefits | Indicator / Economic Proxy |
|---|---|---|
| Economic | Increase in property value | Property value evolution (EUR/$m^2$) |
| | Access to new financing opportunities | Approved funds and access to new financing lines due to expanding activities and water-related investments; |
| | Increase in number of visitors | Number of visitors / Number of stay-overs; |
| | Attracting qualified Human Resources | Number of research/grey publications having the WRL as a case study; |
| | Increased agriculture production | Kg/$m^2$; Farming irrigated area expansion |
| | Consulting services | Revenue from external consulting |
| Social | Increase in well-being | Social questionnaire |
| | Increase community unity and feeling of belonging and rooting in the landscape | Social questionnaire |
| Environmental | Carbon Storage | InvEST Modelling |
| | Water purification | InvEST Modelling |
| | Sediment retention | InvEST Modelling |
| | Increased biodiversity | |
| | Decreased water use and water pressure | |

The key costs initially identified were:

**Table 6.13-2: Main costs identified by the BASE Team together with Tamera representatives**

| | Costs | Indicator / Economic Proxy |
|---|---|---|
| Economic | Construction costs | Direct costs + Project costs + Indirect Tamera Costs |
| | Licenses, Fees, Taxes | ARH Taxes; Licensing fees; |
| | Insurance | |
| | Maintenance of the system | Sediment removal; Pumps Maintenance; |
| | Loss of farming area | Square meters |
| Social | Well-being decrease during construction | Social questionnaire |
| | Disunity within the community | Social questionnaire |
| | Loss of well-being due to externalities (mosquitos, etc.) | Social questionnaire |
| Env. | Pollution during construction | $CO_2$ Emissions |
| | Habitat destructions | Loss of original grassland / Montado |

Regarding the costs and benefits identified by the community members during the PBCA workshop:

**Table 6.13-3: Benefits and costs identified by Tamera community members in the PBCA workshop**

| | Benefits | Costs |
|---|---|---|
| Econ. | Food sovereignty | Construction costs (including re-rooting existing roads) |
| | Affordable lifestyle | Increased taxes and license fees |
| | Increasing guests/visitors | Labour intensity |
| Social | Global healing | Displacement |
| | Improved life quality | Finding consensus/decision making |
| | More working opportunities | Bureaucratic restrictions |
| | Water security | Cultural adaptation |
| Env. | Increased biodiversity | $CO_2$ Emissions |
| | Re-activating ecosystem potential | Loss of existing vegetation |
| | Water availability | Change of niche habits/ Disruption with existing habitats |

Regarding the methodological choices for this economic assessment of costs and benefits of the WRL of Tamera and as mentioned before we've used a combination between participatory methodologies which yields qualitative non-expert values, modelling tools for the environmental assessment – InVEST- and literature review for the economic indicators. The Integrated Valuation of Ecosystems Services and Trade-off's (InVEST) is a free, open-source software developed under the Natural Capital project (NatCap) in order to better integrate the biophysical, socio-economic and other dimensions and values of nature into decision-making processes.[67] The underlying reasoning states that ecosystems, if properly managed, yield a flow of services, which are vital to humanity, including the production of goods (e.g., food), life support processes (e.g., water purification), and life fulfilling conditions (e.g., beauty, recreation opportunities), and the conservation of options (e.g., genetic diversity for future use). Despite its importance, this natural capital is poorly understood, scarcely monitored, and—in many cases—undergoing rapid degradation and depletion. To better align ecosystem conservation with economic forces, the NatCap developed InVEST, which quantifies and maps the values of ecosystem services. The modelling suite is best suited for analyses of multiple services and multiple objectives. The current models, which require relatively little data input, can identify areas where investment may enhance human wellbeing and nature.

The **Participatory Benefit-Cost Analysis** (PBCA) is an economic appraisal tool which has been developed and tested by the Climate Change Impact, Adaptation and Modelling (CCIAM) research group, from the cE3c research Center at the Faculty of Sciences, University of Lisbon, under FP7 Project BASE – *Bottom-up Adaptation Strategies for a Sustainable Europe* - in order to assess through participatory methodologies the costs and benefits of different adaptation measures of the Strategic Plan for Climate Change of Cascais (PECAC). It aims to combine the advantages and strengths of multi-criteria analysis with the rationality of Cost-Benefit Analysis (CBA), thereby evolving from the simplicity of the Simplified Participatory Cost-Benefit Analysis (SPCBA) as proposed by the Climate Resilience Framework.[68] PBCA is a hybrid methodology of economic project appraisal, combining interpersonal deliberation and quantitative methodologies.

[67] http://www.naturalcapitalproject.org/InVEST.html
[68] http://training.i-s-e-t.org/module-series-3/

**Step 4 - Data collection**

**Table 6.13-4: Construction costs of the Tamera WRL**

| Name of the lake | External costs* | Overall construction costs |
|---|---|---|
| Lake/Dam 1 | 250,000 | 312,500 |
| Lake “Espaço dos Jovens” | 154,000 | 192,500 |
| Pond/Dam “Office” | 60,000 | 75,000 |
| Lake “Grace Village” | 20,000 | 25,000 |
| Pond/Dam “Aldeia da Luz” | 25,000 | 31,250 |
| **Total** | **509,000** | **636,250** |

Note: *External costs refer to all sub-contracted services not accounting for Tamera’s own resources input.

Although within the WRL we’ve identified and mapped 29 lakes or small ponds in the research we could only trace back reliable financial data for the biggest lakes having in mind that some lakes/ponds were already existing prior to 2005, other were accounted for in the big lakes costs and for many other small lakes there is no data available. For the CBA we’ve considered that the total amount invested in the lakes construction in Tamera in the period 2005-2014 was 636,250 EUR.

**Licensing, Fees and Taxes Costs**

The EU Directive No. 2000/60/CE, transposed to national legislation by the Law No. 58/2005 (Water Law) and later updated to national law-decree 226-A/2007 on the 31st May and whose later version comes from 2012 – Law No. 44/2012 from 29th August - considers that all uses of water are obliged not only to map, identify and name their water sources and uses but also pay a tax on the use of water resources (TRH). The TRH has five key components (A|E|I|O|U) with a cumulative calculation formula. Tamera’s calculus amounts to 38,037 EUR per year. However, it only takes into account component A and U as the WRL is not yet fully legalized/authorized by the ARH-Alentejo (Hydric Resources Agency Alentejo). According to the mentioned legal framework the fee for not having the proper authorization/license for the use of its water resources, Tamera can be forced to pay between 60,000 EUR and 2.5 M EUR (Law No. 44/2012). For the purpose of our analysis we’ve considered the lowest fine of 60,000 EUR as it is the most common in recent law suits.

**Ecosystem services and Environmental indicators: Invest data collection**

As previously referred, InVEST v.3.0.1 was the tool chosen to model and map in a spatial explicit way the selected ecosystem services in the study area and it contains different sub models, one for each ecosystem service. This modelling tool has been widely used in a variety of studies (e.g. see: Bangash et al., 2013; Leha et al., 2013, Harmáckováa et al., 2014) and has been applied to understand how land cover changes affect different ecosystem services (e.g. Tallis et al 2011; Tallis and Polasky, 2011). In the present study carbon storage, nutrient retention: water purification and sediment retention were the selected ecosystem services to evaluate the land use changes due to artificial lake construction (Zedler and Kercher 2005).

The carbon storage InVEST sub-model is based on four carbon pools - above ground biomass, below ground biomass, soil, dead organic matter (Tallis et al., 2011) and employs a simplified carbon cycle that maps and quantifies the amount of carbon stored and sequestered (e.g. Leha et al., 2013) for the past and current land cover. Therefore, for this ecosystem service to be assessed it was required information regarding current land use and land cover (Base Landscape), past land use and land cover and values of carbon pools (aboveground, belowground, soil, dead organic matter) for the study area climate and taking in consideration the different land cover types. Water purification: the assessment of this ecosystem service with InVEST can be done calculating nutrients retention, using nitrogen (Tallis et al., 2011). Therefore, the nitrogen leaching was interpreted as the ecosystem service of water purification and was calculated based on the amount of nitrogen loadings (inputs) and landscape capacity to retain nitrogen (Tallis et al., 2011). InVEST sediment retention sub model is a three-step approach to evaluate this ecosystem service. First, the potential soil lost (eroded soil) is estimated from each cell using the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). Secondly, it calculates the service of erosion control, which is the capacity of the landscape to retain sediment, taking in consideration the different land-cover types. Finally, sediment discharge will be the difference from received (from upstream cells) and exported sediment

**Table 6.13-5: Trade-offs between non-targeted ecosystems services caused by the construction of artificial lakes**

| | carbon | water purification | | | sediment retention | | |
|---|---|---|---|---|---|---|---|
| year | Carbon storage (Mg ha$^{-1}$) | Nitrogen input (Kg ha$^{-1}$ year$^{-1}$) | Nitrogen retained Kg ha$^{-1}$ year$^{-1}$) | Nitrogen leaching (Kg ha$^{-1}$ year$^{-1}$) | sediments loss (ton ha$^{-1}$ year$^{-1}$) | sediments retained (ton ha$^{-1}$year$^{-1}$) | sediments discharge (ton ha$^{-1}$ year$^{-1}$) |
| 2006 | 75.22 | 4.85 | 4.62 | 0.23 | 1.12 | 1.08 | 0.034 |
| 2014 | 82.27 | 5.07 | 4.84 | 0.23 | 1.73 | 1.64 | 0.080 |
| Δ 2006- | 7.05 | 0.22 | 0.22 | 0.001 | 0.61 | 0.56 | 0.046 |

Our results confirm the role of artificial lakes in the sequestration as a contributing to the mitigation and adaptation to climate changes (Travik et al. 2009, Williamson et al. 2009). In fact, the land cover between 2006 and 2014 showed an overall increase in carbon (year) (9.4%), causing positive carbon storage. This overall result was mainly due to the replacement of grasslands for lakes. Indeed, when land change occurred from broad-leaf forest to water body the difference in carbon storage was negative. Thus carbon storage is positive depending of the land use and land changes that is replaced. Here we show that, only looking to carbon storage, reforestation by natural broad-leaf forest (*Montado*) might be a better strategy regarding the improvement in this ecosystem service for climate change adaptation (Cañellas et al. 2008).

Our results show an increase in the total nitrogen leaching to the landscape. Since it is known that lakes are not significant nitrogen sources, the artificial lakes *per se* are not responsible for the nitrogen increase in a system. However, one of the objectives of the construction of artificial lakes in the study area was to allow the development of agriculture, a major nitrogen source. This may explain the differences found in nitrogen leaching, although the extra nitrogen added did not exceeded the critical loads for broadleaved deciduous and Mediterranean evergreen *Quercus* woodlands: 10-20 kg nitrogen year$_{-1}$ (Bobbink and Hettelingh, 2011).

**Table 6.13-6**

| | |
|---|---|
| Value of C (US$/Ton) | 117.44 |
| Market discount in price of C (%) | 3.5 |
| Annual rate of change in C price (%) | 2.23 |

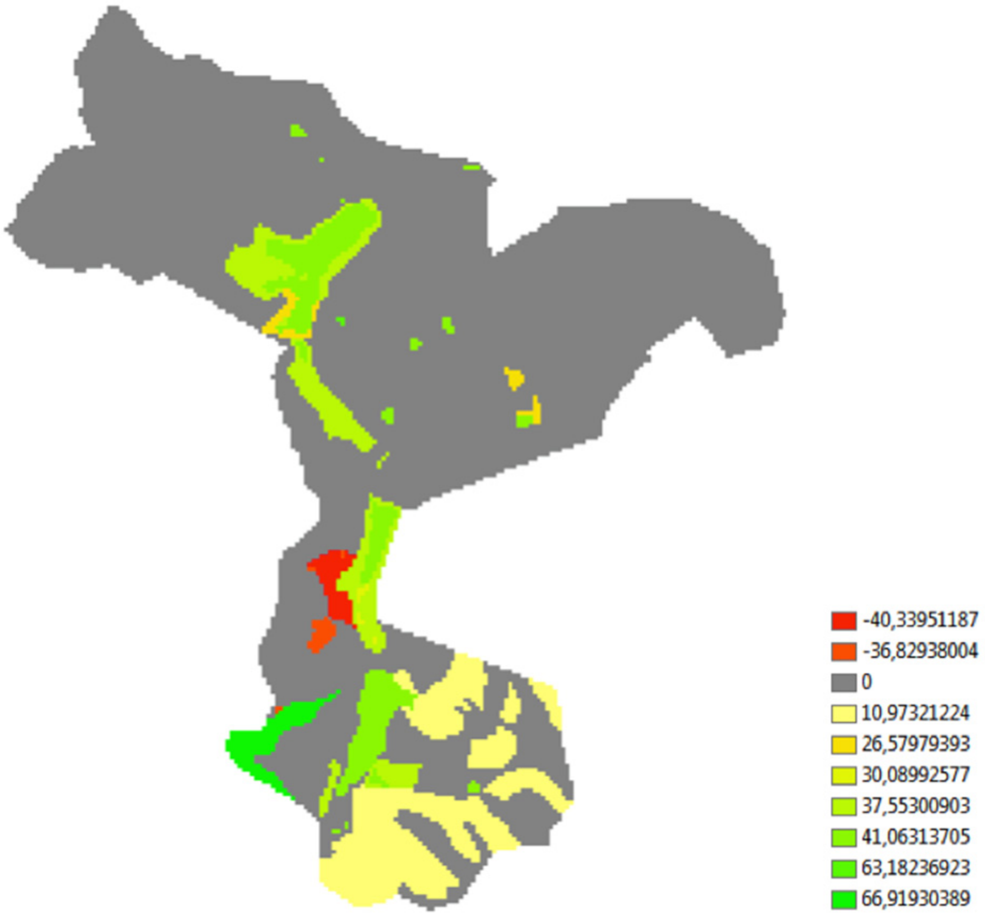



**Figure 6.13-10: Economic value of C sequestered between 2006 and 2050 (US$ per grid cell 10m*10m)**

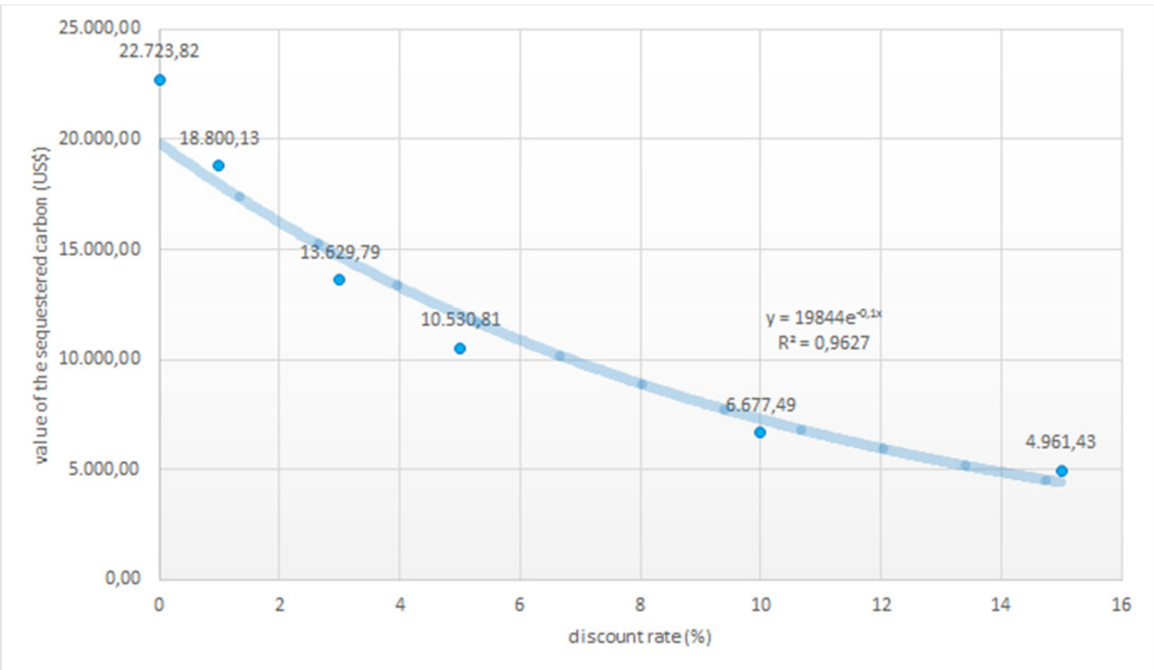



**Figure 6.13-11: Value of total sequestered carbon with different discount rates (US$)**
Source: Branquinho et al (2015)

**Benefits from increased number of visitors/water-related events**

The WRL is an iconic investment and since the beginning of its construction it has attracted many people not only due to the holistic design but also due to the impact it has in the community life of Tamera. We've taken into account the increase number of visitors and water-related events since 2008, namely the average number of participants in the Water Symposium since 2011, the visitors during the Open Days with Permaculture Designer Sept Holtzer since 2008 as well as the Permaculture Seminars with Sept Holtzer also since 2008. Having into account an average spent of 50 EUR per day in Tamera and the average fees for the trainings, the overall economic benefit can be accounted for:

| Event | Average number of participants per year* | Estimated net income for 2014-2050 |
|---|---|---|
| Water Symposium | 100 | 500,000 |
| Permaculture Sept Holtzer Open Days | 100 | 100,000 |
| Permaculture Sept Holtzer Seminars | 35 | 35,000 |
| Water retention Landscape Training | 25 | 175,000 |
| **Total** | | **810,000** |
| **Total discounted (3%)** | | **243,000** |

Note: Last 7 years or 5 in the case of the Water Symposium.

**Social and agriculture benefits of the WRL**

Both the scientific experts and the members of the community highlighted the role of water in the landscape as a crucial element for social and environmental wellbeing and a thriving society, especially in semi-arid regions. In our research process a questionnaire was foreseen in order to scientifically measure and quantify that perceived benefit and social impact of the WRL. Due to time and resources limitations this was not possible to implement during BASE research process. Nevertheless, this important benefit was internalized when we take into account that the market valuation of land and the price elasticity of rural property are tightly connected with water availability, storage and water quality. This premium price of water varies in the literature, however for semi-arid regions it can fluctuate between 15% and 40% (ref). Applying this premium coefficient to Tamera's land value we've estimated an approximate benefit of 150.000 EUR to 400.000 EUR[69]. For the purpose of our analysis we've considered the highest premium of 40%, with a discounting of 3%.

[69] Tamera's Land Value according to a Bank evaluation done by Crédito Agrícola in 2005 is approximately 1M€.

**Step 5 – NPV Calculation and discussion of results**

The criteria used to assess the overall social welfare impact of the WRL in Tamera is the Net Present Value, which accounts for the sum of all discounted benefits for the period minus the sum of all discounted costs in a single monetary common unit – the EUR. We've used the time period of 2015 to 2050 and a discount rate of 3%.

NPV (net present value) = ∑ Bt (1+i)-t - ∑Ct (1+i)-t

∑ Bt = Land value increase + Increased number of visitors and Water-related events + Ecosystems services

∑ Bt = 142.153 EUR + 243.000 EUR + 12.000 EUR

∑ Bt = 397.153 EUR

∑Ct = Construction costs + Licensing Fine + TRH Annual Fees

∑Ct = 636.250 EUR + 60.000 EUR + 7.315 EUR

∑Ct = 703.565 EUR

NPV = 397.153 EUR - 703.565 EUR

NPV = - 306.000 EUR

The NPV of the WRL of Tamera regarding the variables and proxy's considered is negative in 306,000 EUR. The high costs involved in the construction of the lakes are not overtaken by the discounted benefits, which would be a strong argument against the development of the 1,000 Lakes for the Alentejo vision. However, we must acknowledge that slight changes in the discounting of benefits would have a major impact in the NPV – e.g. a 0% discount rate would yield a positive NPV – as well as if we take into consideration that the price of water is expected to increase over the next years and the value of resilient ecosystems will be much valued in such semi-arid regions. We have decided not include such projections as uncertainty and competing theories for such important factors undermine scientific consensus. Finally, another important variable, which was excluded, was increased agriculture production due to lack of reliable data and direct causal link with the WRL. Further research in the future might include this and contribute to a more balanced NVP.

**Annex**

**Table 6.13-7**

| Type | Index Name | Calculation | Drought Classification | Strength | Weakness | References and Applied Area |
|---|---|---|---|---|---|---|
| Meteorological drought | Palmer Drought Severity Index (PDSI) | Based on a 2-layer bucket-type water balance model, the PDSI measures the departure of moisture balance from a normal condition | −4.0 or less: extreme drought; −3.0 to −3.99: severe drought; −2.0 to −2.99: moderate drought; −1.0 to −1.99: mild drought; −0.5 to −0.99: incipient dry spell; 0.49 to −0.49: near normal | Considers both water supply (precipitation) and demand (potential evapotranspiration) | Does not work well over mountainous and snow covered areas; may require re-normalization | Refs 22–24; mostly the United States, but also globe |
| | Standardized Precipitation Index (SPI) | Fitting and transforming a long-term precipitation record into a normal distribution with respect to the SPI, which has zero mean and unit SD. | −2 or less: extremely dry; −1.5 to −1.99: severely dry; −1.0 to −1.49: moderately dry; −0.99 to 0.99: near normal | Can be computed for different time scales; symmetric for both dry and wet spells; relates to probability | Requires long-term precipitation data; no consideration of evaporation | Refs 25, 26; any area by drought planners |
| | Rainfall Deciles (RD) | Ranking rainfall in the past 3 months against the climatological record of 3-month rainfall, which is divided into 10 quantiles or deciles | deciles 1–2 (lowest 20%): much below normal; deciles 3–4: below normal; deciles 5–6: near normal | Provides a statistical measure of precipitation; performed well in limited tests | Requires long-term precipitation data; no consideration of evaporation | Ref 27; Australia |
| Agricultural Drought | Computed Soil Moisture (CSM) | Soil moisture content is computed by a land surface model forced with observed precipitation, temperature and other atmospheric forcing | Drought may be defined based on the percentiles of the CSM, e.g., ≤20th percentile: very dry; 20–40%: dry; 40–60%: near normal | Considers antecedent conditions | Requires atmospheric forcing data and a land surface model | Refs 28–30; the United States, globe |
| | Palmer Moisture Anomaly Index (*Z*-index) | The *Z*-index is the moisture anomaly for the current month in the Palmer model | Percentiles of the *Z*-index may be used to define drought | Rapid response to current precipitation deficit | Does not consider antecedent conditions | Refs 22, 24; the United States |
| Hydrological Drought | Total water deficit ($S$) | $S = D \times M$, where $D$ is the duration during which the streamflow is below the normal level and $M$ is the average departure of streamflow from the long-term mean during period $D$ | $S$ may need normalization in defining drought | Simple calculation | No sub-basin information, no standard drought classification | Ref 31; the United States |
| | Palmer Hydrological Drought Index (PHDI) | Computed using the same Palmer model as for the PDSI, but with a more stringent criterion for the termination of the drought or wet spell | Values similar to PDSI, but with smoother variations | Use of a water balance model to account for the effect of both precipitation and temperature | Does not work well over mountainous and snow covered areas; may require re-normalization | Ref 22; mostly the United States |
| | Surface Water Supply Index (SWSI) | Calculated by river basin based on snowpack, streamflow, precipitation, and reservoir storage | Normalized values similar to PDSI | Considers snowpack and water storage | Basin-dependent formulations | Refs 32, 33; the western United States |
| Regional Drought | Drought Area Index (DAI) | Percentage of a given region under drought condition based on a drought intensity index | Drought is defined based on a separate index | Quantifies drought areal extent | Does not provide the mean intensity of drought over the region | Ref 34; anywhere |
| | Drought Severity Index (DSI) | Area-weighted mean of a drought intensity index over the drought area in a given region | Drought is defined based on a separate index | Quantifies drought severity over a region | Does not provide drought areal extent | Ref 35; anywhere |

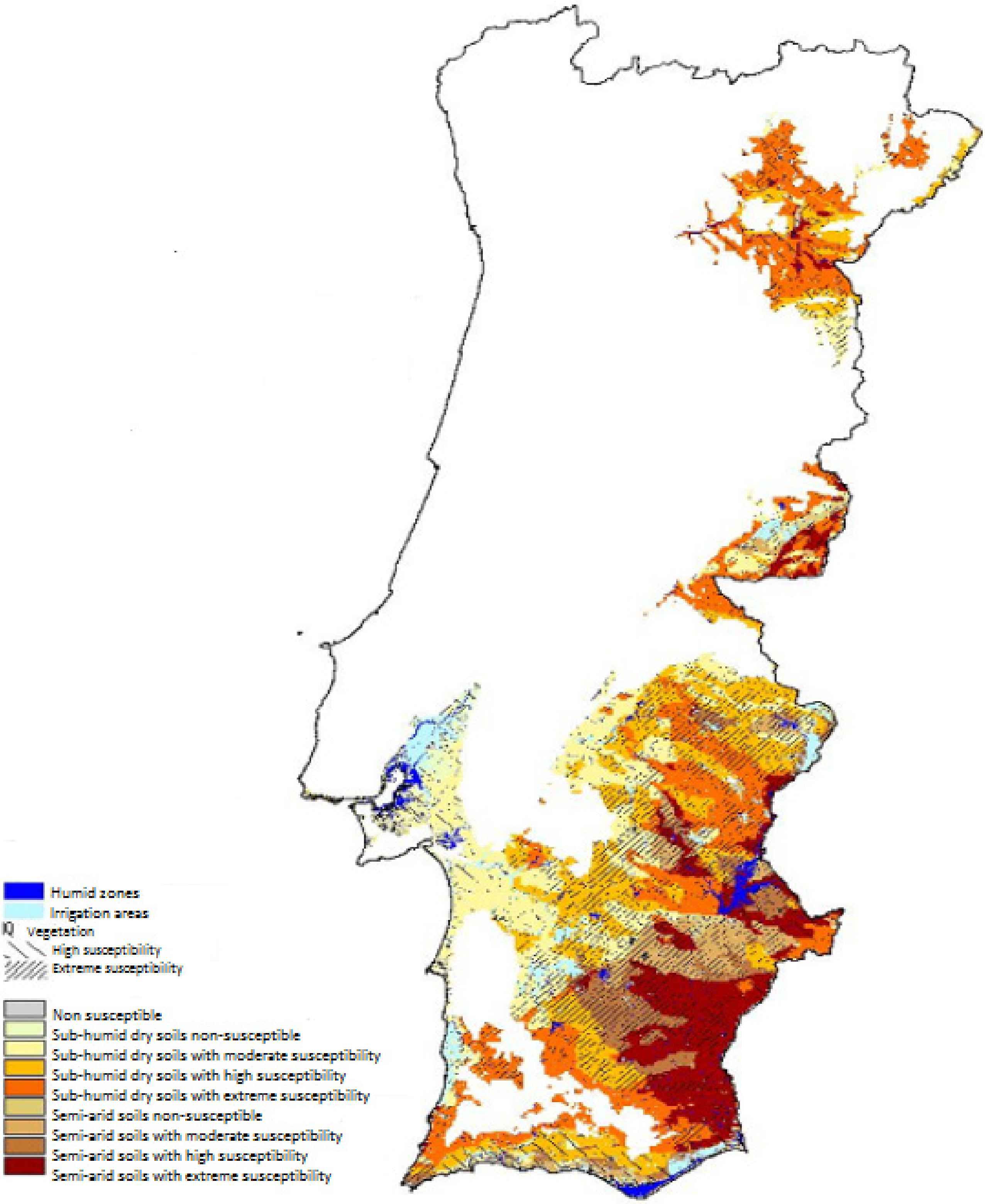



**Figure 6.13-12: Comparison of commonly-used Drought Indices**
Source: Dai (2011)

Table 6.13-8

| Nº ID of the resource | Name | Tipo de Captação | Estado Administrativo do Processo (1) | Utilização da Água | Caudal de Exploração Médio ($m^3$/hora) | Volume Médio Anual Extraído ($m^3$) | Volume Máximo Mensal Extraído ($m^3$) | Nº de Horas Médio em Extração | Área dos Lagos ($m^2$) | Ano de Construção |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 20 | Charca "Vale Yin de Cima" | Charca ** | Reg. 14.12.2010 *** | ocupação de terreno | -/- | -/- | -/- | -/- | 1075 | 2012 |
| 1 40 | Charca "Vale Yin de Baixo" | Charca * | Reg. 14.12.2010 *** | ocupação de terreno | -/- | -/- | -/- | -/- | 1100 | 2009 |
| 1 60 | Charca "Dos Cavalos" | Charca * | Reg. 14.02.2010 *** | Rega | 1,5 | 225 | 40 | 150 | 450 | 2006 modificado 2008 |
| 2 00 | Charca "das Rochas" | Charca* | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 600 | antes 1994 |
| 3 00 | Charca/Barrag "Lago1" | Charca ** | Reg. 14.02.2010 *** | Rega | 2 | 600 | 100 | 300 | 6400 | 2007 |
| 4 00 | Albufeira "Torre" | Charca * | Reg. 14.02.2010 *** | Reservatório p/ Nº 8 | ------------- | ----------- | ----------- | ----------- | 180 | 2005 |
| 5 00 | Charca "Lago Cinzento" | Charca ** | 1451_2004 DALBA | Rega | 1,5 | 225 | 40 | 150 | 1400 | antes 1994 |
| 6 00 | Lago "Espaço dos Jovens" | Charca * | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 900 | antes 1994 modificado 2007 |
| 7 00 | Charca "Escritório" | Charca ** | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 625 | antes 1994 modificado 1999 |
| 8 00 | Lago "Olival" | Charca * | 1639_2005 DALBA | Rega | 0,3 | 270 | 50 | 900 | 50 | 2005 |
| 9 00 | Charca "Casa das Crianças" | Charca * | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 250 | antes 1994 |
| 10 00 | Charca "Casa de Campo" | Charca ** | 1638_2005 DALBA | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 1470 | 2004 |
| 11 00 | Lago "Lírio de Água" | Charca * | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 200 | 2007 |
| 12 00 | Lago "Horta do Vale" | Charca ** | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 2450 | 2008 |
| 13 00 | Albufeira p/ "Horta do Vale" | Charca * | Reg. 14.02.2010 *** | Reservatório p/ Nº 3 | ------------- | ----------- | ----------- | ----------- | 150 | 2005 |
| 14 00 | Lago "Aldeia do Vale" | Charca * | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 860 | 2008 |
| 15 00 | Lago "Aldeia Grace" | Charca ** | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 1125 | 2009 |
| 16 00 | Lago "das Silvas" | Charca * | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 500 | antes 1994 |
| 17 00 | Charca "Aldeia da Luz" | Charca ** | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 800 | 2007 modificado 2011 |
| 18 00 | Charca "Lago Castanho" | Charca ** | 1452_2004 DALBA | Rega | 1,5 | 225 | 40 | 180 | 1575 | antes 1994 |
| 18 50 | Charca "Lago Sul" | Charca ** | Reg. 14.12.2010 *** | Ocupa. Terreno | -/- | -/- | -/- | -/- | 3550 | 2010 |
| 19 00 | Lago "Espaço Yin Pequena" | Charca * | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 225 | antes 1994 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20 00 | Charca/Barrag "Triângulo" | Charca ** | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 400 | antes 1994 |
| 21 00 | Charca "Horta do Pastor Baixa" | Charca * | Reg. 14.02.2010 *** | Rega | 1,2 | 216 | 40 | 180 | 100 | 2009 modificado 2011 |
| 22 00 | Charca/Barrag. "Santuário" | Charca ** | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 2100 | antes 1994 |
| 23 00 | Lagoa "Vale Mua 2" (=Sul 2) | Charca ** | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 750/> 8000 | 2007 modificado 2011 |
| 24 00 | Charca p/ F4 Monte cabana | Charca * | Reg. 14.02.2010 *** | Reservatório p/ Nº F4 | ------------- | ----------- | ----------- | ----------- | 300 | 2006 |
| 25 00 | Charca/Barragem "Pueblo" | Charca ** | 1453_2004 DALBA | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 2000 | 1997 |
| 26 00 | Charca/Barragem "Aurélio" | Charca ** | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 1200 | antes 1994 |
| 27 00 | Charca/Barra."Casa Vale Mua" | Charca ** | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 1350 | 2006 |
| 28 00 | Charca "Vale do Sul" | Charca * | Reg. 14.02.2010 *** | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 600 | antes 1994 |
| 29 00 | Charca "Tamir" | Charca ** | | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 700 | 2011 |
| 30 00 | Charca "Rico" | Charca * | | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 400 | 2011 |
| 31 00 | Charca "Amarelo" | Charca * | | Ocupa. Terreno | ------------- | ----------- | ----------- | ----------- | 500 | 2011 |
| F 1 | Furo "Oficina" | Furo Vertical | 1447_2007_ SB | Rega **** | 1,8 | 300 | 25 | 167 | --------- | 1998 |
| F 2 | Furo "Campus" | Furo Vertical | 1448_2007_ SB | Rega **** | 1,8 | 300 | 25 | 167 | --------- | 2004 |
| F 3 | Furo "Children Place" | Furo Vertical | 1710/CSB/SD/2008 2468-2009-DRHI | Rega **** | 1,8 | 3900 | 400 | 2167 | --------- | 1998 |
| F 4 | Furo "Monte Cabana" | Furo Vertical | 1711/CSB/SD/2008 2468-2009-DRHI | Rega | 0,9 | 1950 | 200 | 2167 | --------- | 1998 |
| F 5 | Furo "Casa das Crianças" | Furo Vertical | Reg. 14.02.2010 *** | Rega **** | 0,7 | 70 | 20 | 100 | --------- | 1998 |
| P 1 | Poço "Vale da Fonte" | Poço | Reg. 14.02.2010 *** | Sem uso | ------------- | ----------- | ----------- | ----------- | --------- | antes 1994 |
| P 2 | Poço "Horta de Pastor" | Poço | Reg. 14.02.2010 *** | Rega | 1,2 | 216 | 40 | 180 | --------- | antes 1994 |
| P 3 | Poço "Vale da Mua" | Poço | Reg. 14.02.2010 *** | Sem uso | ------------- | ----------- | ----------- | ----------- | --------- | antes 1994 |
| P 4 | Poço "Lago Sul" | Poço | | Rega | | | | | | 2012 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| M 1 | Mina / Fonte "Oráculo" | Mina / Fonte | Reg. 14.02.2010 *** | Rega | 0,02 | 170 | 15 | 8600 | --------- | antes 1994 |
| M 2 | Mina / Fonte "Vale da Fonte" | Mina / Fonte | Reg. 14.02.2010 *** | ------------- | ------------- | ----------- | ----------- | ----------- | --------- | antes 1994 |
| 02 00 | Espace de Chriancas | Fossa | Reg. 14.12.2010 | ------------- | ------------- | ----------- | ----------- | ----------- | --------- | 2010 |
| 03 00 | Campus & Aula | Fossa | Reg. 14.12.2010 | ------------- | ------------- | ----------- | ----------- | ----------- | --------- | 2002 |
| 04 00 | Casa de Campo | Fossa | Reg. 14.12.2010 | ------------- | ------------- | ----------- | ----------- | ----------- | --------- | 2010 |
| 05 50 peq | Casa de Criancas | Fossa pequena | sem | ------------- | ------------- | ----------- | ----------- | ----------- | --------- | 2010 |
| 06 00 | Aldeia Solar & Aldeia Luz | Fossa | Reg. 14.12.2010 | ------------- | ------------- | ----------- | ----------- | ----------- | --------- | 2009 |
| 07 50 peq | Aldeia Grace | Fossa pequena | sem | ------------- | ------------- | ----------- | ----------- | ----------- | --------- | 2006 |

## 6.14 South Aveiro Coast

Inês Campos, André Vizinho and Filipe Moreira Alves, FFCUL

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

**Coastal erosion**

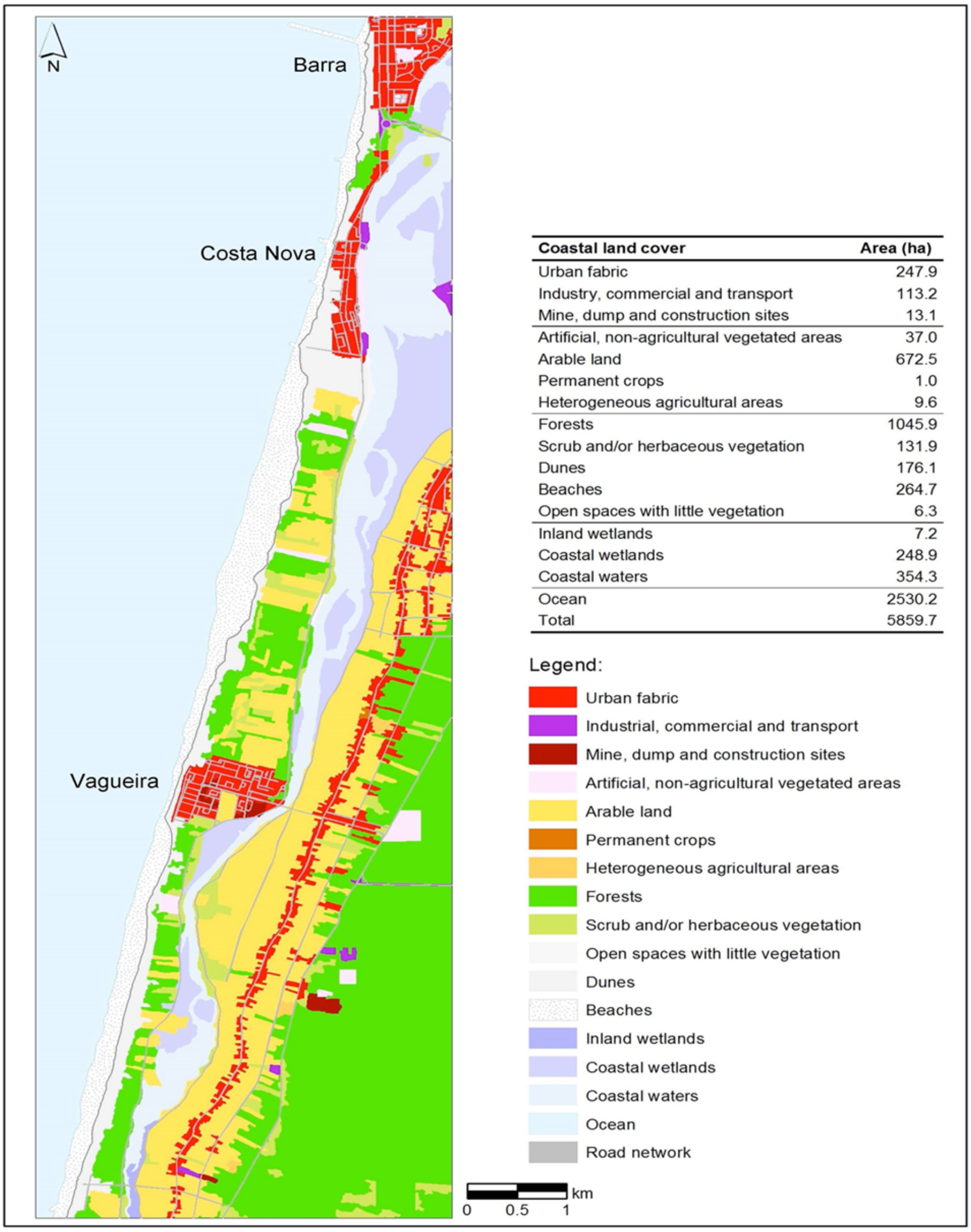
Coastal zones in Europe experience increased rates of erosion due to rising sea levels, increased storm surge frequencies, reduced sediment delivery to the coast, as well as anthropogenic degradation and transformation of natural coastal areas (EEA, 2006; Roebeling et al., 2013). Although the impacts of coastal erosion are confined to coastal areas, these areas host between 15% (<10 km from coast) and 40% (<100 km from coast) of the world population (EEA, 2006) as well as a wide variety of built and natural capitals that provide corresponding services. The Central Portuguese coast is a highly energetic sandy coast, with a typical wave regime from the northwest. Potential alongshore sediment transport is mainly due to wave action, with values of between 1 and 2 m m3/year (Oliveira, 1997).

Coastal erosion is mainly due to rising sea levels, artificialization of natural areas, port construction works and reduced sediment supplies from natural sources (Coelho et al., 2009) – the latter being considered the main cause of coastal erosion along the Central Portuguese coast (Silva et al., 2007). Three main coastal erosion adaptation pathway scenarios have been identified for the Barra Vagueira coastal stretch (see Perreira, 2014). These adaptation pathways comprise combinations of soft as well as hard intervention measures that are expected to completely halt land losses in the area.

Scenario 1 entails artificial beach nourishments of urban fronts with a large volume of sediments in combination with minor hard intervention measures; Scenario 2 entails artificial beach nourishments of urban fronts with a medium volume of sediments in combination with moderate hard intervention measures; and Scenario 3 entails artificial beach nourishments of urban fronts with a small volume of sediments in combination with major hard intervention measures.

Coastal erosion along the Central Portuguese coast is mainly due to rising sea levels, artificialization of natural areas (including coastal protection measures), port construction works and reduced sediment supplies from natural sources (Coelho et al., 2009). The reduced sediment supply, resulting from the diminished sediment loads from the Douro river, is considered the main cause of coastal erosion problems along the Central Portuguese coast (Silva et al., 2007). Under natural conditions Douro river sediment supply values ranged between 1.5 and 2.0 m m3/year – now sediment supply remains below 0.25 m $m^3$/year (Bettencourt, 1997). This difference is explained by in-river works and actions (e.g. dam construction, navigation dredging, sand extraction and shore protection) as well as catchment land use and practice changes (Coelho et al., 2009). In this study we consider only part of the Central Portuguese coast – i.e. the coastal zone between Barra (Ílhavo municipality) and Praia do Areão (Vagos municipality).

The study area is defined for a coastal sector of 14.0 km length and 4.2 km width (58.6 km2), including a coastline of about 14.5 km length with a general orientation of NNE-SSW. The study area covers a total of 5,860 ha (land and ocean), extending through three municipalities: Ílhavo, Vagos and Mira. These represent a relatively small percentage of the total municipality area – less than 15%, 18% and 1%.).




| Coastal land cover | Area (ha) |
|---|---|
| Urban fabric | 247.9 |
| Industry, commercial and transport | 113.2 |
| Mine, dump and construction sites | 13.1 |
| Artificial, non-agricultural vegetated areas | 37.0 |
| Arable land | 672.5 |
| Permanent crops | 1.0 |
| Heterogeneous agricultural areas | 9.6 |
| Forests | 1045.9 |
| Scrub and/or herbaceous vegetation | 131.9 |
| Dunes | 176.1 |
| Beaches | 264.7 |
| Open spaces with little vegetation | 6.3 |
| Inland wetlands | 7.2 |
| Coastal wetlands | 248.9 |
| Coastal waters | 354.3 |
| Ocean | 2530.2 |
| Total | 5859.7 |

**Figure 6.14-1: Land cover in 2010 for the case study area**

**Coastal erosion and flood damage assessment**

Direct coastal erosion and flood damages, related to the physical impact of coastal erosion and floods on humans, properties and activities in affected areas, are assessed following four basic steps (see Merz et al, 2010). First, elements at risk are classified by pooling objects at risk into uniform classes and, in turn, assessing damage for these different classes. This classification is based on built and natural capital classes, including residential, industrial, infrastructure, and agricultural and natural land cover classes. Second, the exposure of these classes to coastal erosion and flooding is analysed by intersecting land cover maps with shoreline evolution and inundation data, using geographic information systems. Third, assets are assessed by estimating asset values for those classes exposed to coastal erosion and flooding risk. Finally, susceptibility to coastal erosion and flooding is analysed by relating the damage for the respective classes at risk to characteristics of shoreline evolution and inundation. In the case of flooding, damage functions are used that represent the susceptibility of the class at risk as a function of water depth and frequency of inundation. The uniform classes used in the coastal erosion and flood damage assessment studies, are based on land use / land cover data for the year 2007 (COS2007, 2007; see 6.14-1). Land cover data were updated to those for 2010, using satellite imagery from Google Earth[70] and imagery from Google Street View[71].

**Coastal erosion damage assessment**

The numerical Long Term Configuration model (LTC) is used to simulate medium (10 year) to long-term (50 year) shoreline evolution patterns and resulting land cover loss, as a function of intervention measures (see Coelho, 2005; Coelho et al., 2007). It combines a classical one-line model with a rule based model, and is designed for sandy coastlines, where the main cause of shoreline evolution is the alongshore sediment transport – the latter essentially dependent on the wave regime, the sediment characteristics and the sand availability. Using three-dimensional topographic data that is continuously updated during simulation, the model assumes that each wave acts during a certain period of time (computational time step) and is able to generate sediment transport. The volume of alongshore sediment transport is given by the continuity equation, and is distributed along the active profile between the closure depth and wave run-up limit according to predetermined rules. The alongshore transport rates are estimated through the application of formulae that depend on the shoreline-to-wave angle, the wave height and, in some cases, the beach slope and the sediment grain size. The wave transformation by refraction, diffraction and shoaling is modelled in a simplified manner, or, wave conditions may be imported from more complex wave models. Shoreline changes are, hence, determined by gradients of the alongshore transport rates between adjacent beach cells – as in the case of classical one-line models.

The impact of different intervention measures on shoreline evolution and resulting land cover class losses can be assessed using the LTC model. In this study the LTC model is used to assess shoreline evolution and land cover class losses over the period 2010 to 2050, considering no additional intervention measures (i.e. business-as-usual; see Perreira, 2014). The exposure of land cover classes (*i*) to coastal erosion is established for this baseline scenario using land cover maps (COS2007, 2007) and built area maps (Google Earth), allowing for the determination of the eroded land cover class areas ($E_i$; in ha). Land cover class values ($v_i$) are determined, and corresponding costs from coastal erosion ($C_{erosion}$; in m EUR) are calculated as follows:

**Flood damage assessment**

Historical flooding data, land cover maps and land cover values are used to assess direct impacts and costs from overtopping in artificialized areas. First, flood scenarios for the case study area are established based on historical inventories of overtopping events in Central Portugal (Perreira and Coelho, 2010), allowing for the determination of inundation frequency and severity (height/intrusion). Second, the exposure of land cover classes (*i*) to flooding is established for these flood scenarios using land cover (COS2007, 2007) and built area (Google Earth) maps, allowing for the determination of the flooded land cover class areas ($F_i$; in ha). Note that considered land cover classes include artificialized areas, only. Third, artificialized land cover class values ($v_i$) are determined for structure and content, and potential damage costs are assessed using depth-damage-functions (DDFs) for structure and contents (based on Davis and Skaggs, 1992). The DDFs take the following form:

where $D_i$ is the rate of damage to structure or content (in % of their respective value $v_i$) and $H_i$ is the height of inundation (in m). Finally, structure and content costs of a flooding event ($C_{flood}$; in) are calculated as follows (Oliveri and Santoro, 2000):

=Σiflood i i i

**Steps 2 & 3– Identification of Adaptation Measure and Adaptation Pathways &Evaluation Criteria and Method**

**Structural measures for coastal defence**

In general, the mitigation of the coastal erosion problem can be seen in two different ways, considering acting on the causes of the erosion (the sediments deficit) or acting over the consequences, trying to reduce the losses or

[70] https://www.google.com/earth.
[71] https://www.google.com/maps/views/streetview

damages. The cause of coastal erosion is the sediment deficit in the coastal system. It is understood as acting on the causes, any measure implanted to reduce this sediments deficit in the coastal system. Such measures can be taken to decrease the impact of anthropogenic actions on the sediment volumes supplied to the coast (reducing effect off dams or breakwaters, for instance), or in order to artificially provide sediments to the coastal system. It is understood as acting on the consequences, all measures that promote reducing the exposure of urban water fronts to wave actions or coastal erosion, and consequent overtopping, flooding and damage to infrastructures. These measures may be in order to relocate populations and constrain the use of the most vulnerable areas, thereby decreasing the length of exposed coastline, or to protect the infrastructure and buildings through coastal defence works. The following text summarizes a diversity of potential structural intervention measures against the phenomenon of coastal erosion. All these actions can be considered separately or combined simultaneously.

**Artificial beach nourishment**

This is an intervention for the prevention of coastal erosion. The choice of material to transfer to the beach should consider sediments grain size and density of the material existing on the beach. For this reason, the scenarios considered are not expected to use dredged material from the Ria de Aveiro, because all preliminary indications suggest that these sediments will not have the quality required for beaches nourishments (these sediments were only considered in the dunes reinforcement). The artificial beach nourishment protects the coastal area where it is performed, but also the stretches at south (down drift) that over time will benefit from the effect of the sediment transport. Besides the protective effect, the addition of sand keeps the recreational and environmental value of the beach. However, artificial beach nourishment requires the existence of sediments source (dredging) and the need for frequent re-nourishment operations, having in mind that the loan sediment zones tend to be located in remote areas, as it the closer sources dwindle the supply.

*Advantages:*

- Allows the maintenance of beaches, which are, by their nature, the preferential morphology for coastal protection;
- Enlarge and/or maintain environmental and recreational value of the beach;
- After some time, the sediments will also supply the down drift stretches of the intervention location.

*Disadvantages:*

- Originates superior erosion than the one at natural beaches, since in general the profile that results from the artificial nourishment, is not in equilibrium with the wave climate;
- Requires short periods for re-nourishment, with high maintenance costs. There is the possibility to combine this technique with other (detached breakwaters and/or groins), in order to reduce the need for re-nourishment. In the following, specific aspects of different alternative sources of sediment and equipment to perform the nourishment intervention on beaches are presented, applicable in the case of Barra-Mira stretch.

**Sediments from harbour dredging and from the deposit existing at the Aveiro harbour, using road for transport**

This intervention aims to use dredged materials in harbour areas for the artificial beach nourishment. The choice of the equipment involved is associated with the deposition site in the beach profile. The deposition of sediments in the immersed zone allows the use of barges with the opening of the basement, while the placement of sediments at the beach requires the use of a dredger associated with a pumping and piping systems, so that the dredged materials are deposited in beach (with predictably higher costs).

*Advantages:*

- Use of sediments often available;
- Low impact during the operations, in the neighbouring area of intervention;
- Use of dredged materials in the coastal system as an alternative to placement in deposits;
- Possibility of deposition of material in the emerged beach, with immediate gain in recreational value of the beach.

*Disadvantages:*

- Need to control the dredged material characteristics, in terms of quality and compatibility with the sand existing at the beach;
- Availability of sediment, conditioned to the need for dredging of harbour channels;
- During the intervention, due to the movement of a large volume of sediments, there are disturbances with negative impact on the neighbouring area of intervention;
- Probable damage to roadways, resulting from the transport of sediments (heavy trucks) from the place of temporary storage and the intervention site.

**Sediments from São Jacinto**

The sediments accumulation in Sao Jacinto is due to the interruption of longitudinal sediment transport caused by the northern breakwater of the Aveiro harbour. The use of these sediments on the coastal system, south of Barra, represents a form of transposition of sediments (bypass). Nourish beaches in the Barra-Areão stretch using sediment accumulated in San Jacinto has the following impacts:

*Advantages:*

- Sands with suitable characteristics to artificially nourish the beaches;
- Reduce the need for dredging interventions in the harbour channel.

*Disadvantages:*

- Availability of sediment conditioned to the volume of sediment accumulated in Sao Jacinto.

**Sediments from offshore dredging**

Artificial nourishments can be done with sediment obtained by offshore dredging. These sediments are collected with dredges resources in remote areas of the coast, and later placed in the profile of the beaches to nourish.

*Advantages:*

- Low impact on the neighbouring area of the intervention;
- Almost unlimited availability of sediments;
- Possibility of using large equipment, reducing unit costs of each operation.

*Disadvantages:*

- Use of big equipment’s and at larger distances, which can be economically costly, justifying the operation only in situations of large volumes of sediments;
- Need a preliminary evaluation of the existence and location of spots for sediments loan;
- Despite of the removal of sediments be at large depths, could exist potential hydrodynamic and morph dynamic impacts (even if reduced), not yet evaluated.

**Dunes reinforcement**

The reconstruction of weakened sand dune systems is a way to mitigate flood hazards and it is also adequate to deal with some emergency situations. Planting vegetation helps to stabilize the dune. However, it is necessary be aware that the salinized sand postpones the possibility of using vegetation and the size of the sediment influences the vegetation type. Placing palisades encourages the natural process of retaining sand in the dunes and also serves to protect the trampling. It is necessary a loan source of sediments to precede this intervention. The realization of sediment deposits located at specific points of the stretch Barra-Areão (down drift groins or at north of Vagueira) allows to anticipate a volume of material for protection of these most vulnerable areas.

*Advantages:*

- Reduces/prevents overtopping and consequent flooding;
- Gives robustness to the sand dune systems, increasing the volume of sediment available for entering in the coastal system.

*Disadvantages:*

- Possible occupation of private land, with a tendency to retreat of the position of the dune over time.

**Sediments dredged from the Mira channel**

The reinforcement of the dunes using the dredged material from the Mira channel follows the pretence of reclassifying that channel, while allowing use materials from the dredging to give robustness to the adjacent dune system.

*Advantages:*

- Reclassification of Mira channel;
- Proximity between the location of the loan sediments and the dune;
- Use of materials that otherwise should have some costs to a further use.

*Disadvantages:*

- During the operation, there is a negative impact on the populations surrounding the intervention area due to the movement of dredged materials;
- The use of road resources may cause damage to the road network resulting from the transport of sediments from the dredging site to the deposition location;
- The use of sediment is conditioned to the volume of sediments resulting from dredging and the assessment of the respective quality;
- The weak potential quality of dredged sediments may limit the use of these volumes to an inner core of strengthening of the sand dunes, forcing subsequent coating with best quality material;
- Reduced availability of sediments, and limited in time.
- During operations, noise and road traffic.
- Increasing the tidal range in the Aveiro Ria (highest flood risk).
- Decreased seafood at bottom.

**Dunes reinforced using geotextiles**

In the last years, the use of geotextiles in hydraulic works has increased, particularly in the context of coastal defence and rehabilitation of dune systems. In the specific case of geobags and geotubes, it can be prepared by using the filling material (sand), which can be obtained by dredging.

*Advantages:*

- The containment of dredged material in geotextile allows greater longevity of the intervention;
- The intervention will have less visual impact than the works in rock;
- The failure of the intervention can be countered through the elimination and removal of geotextiles.

*Disadvantages:*

- Tends to have a similar impact of seawalls, fixing the position of the shoreline and exposing the geotextile in situations of temporal, with occasional visual impact;
- Require the use of sediment to fill the geotextiles.

**Sediments from harbour dredging**

The maintenance dredging are frequent harbour operations due to the need to maintain the quotas in the channels, to allow for adequate navigability operation on the harbour. This intervention option provides the use of the material resulting from dredging, in reinforcement of the sand dunes.

*Advantages:*

- Utilization of dredged material resulting from dredging often carried out.

*Disadvantages:*

- The reinforcement of the dunes requires the use of road resources, which would cause damage to the road network resulting from the transport of sediments from the place of temporary storage and the location of dune reinforcement;
- The availability of sediments and is reduced limited in time.

**Seawall**

The seawalls correspond to the placement of rock, concrete blocks or geosynthetic material along the slope of the dune or beach. This intervention aims to receive the direct impact of the 18 wave action, reflecting and dissipating wave energy. The seawall allows fixing the longitudinal position of the shoreline (Figure 2).

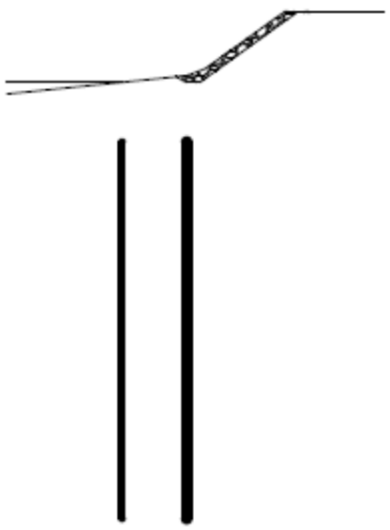


**Figure 6.14-2: Schematic representation of a seawall**

*Advantages:*

- Reduces wave action by absorbing the wave energy in the faces and empty spaces of the seawall;
- Prevents or reduces overtopping;
- Maintains the shoreline position, preventing the loss of territory.

*Disadvantages:*

- Leads to degradation of the recreational and aesthetic value of the beach;
- The reflective effect conjunction with sediment deficit, leads to a progressive decrease in the size of the remaining beaches, tending to its disappearance;
- The deepening of the immersed strip contiguous to the seawall leads to higher waves heights that reach the seawall, leading to an increased frequency of overtopping, flooding, damage to structures and instabilities on the seawall;

- Present an increasing trend of the maintenance costs in time by decreasing the time intervals between maintenance interventions.

**Groins**

A groin is a structure perpendicular to the shoreline, and it is applicable where there are volumes of sediment in transport along the coast. The groins cause the deposition of sand in areas affected by erosion, through the partial or total interruption of the sediments' flow along the coast. So, after the groins construction it is observed the deposition of sediments up drift the structure, creating or extending the existing beach area, but anticipating the erosion down drift of the structure (Figure 6.14-2).

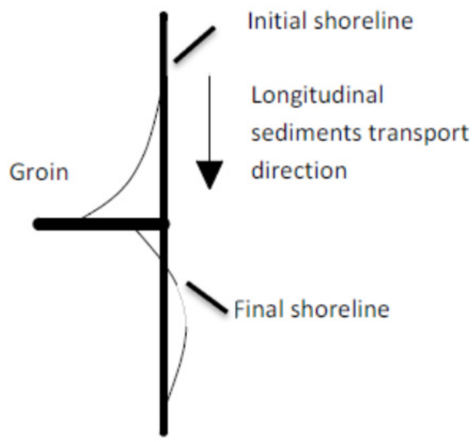



**Figure 6.14-3: Schematic representation of a groin**

*Advantages:*

- Allows rebuilding eroded beaches by the accumulation of sediments up drift (higher and longer groins, greater effectiveness at north);
- Can be combined with artificial nourishments, confining sediment and prolonging the effectiveness of the intervention.

*Disadvantages:*

- Require often maintenance operations;
- Causes negative visual impact, as well as introducing difficulties in the circulation of the public, reducing the aesthetic and recreational value of the beaches;
- Anticipates the down drift erosion process that occurs during the filling process up drift the groin;
- If there is no sediment transport, the groin does not effectively work;
- Are especially vulnerable when the wave direction is from southwest, because the area at south of the groin is usually weakened;
- The root of the groins requires special care to limit the damage at down drift (usually, this vulnerable area is also protected with seawalls).

**Submerged detached breakwaters**

Coastal defence structure parallel to the shoreline, located in the submerged areas, with submerged or emerged crowning. Reduces (dissipates) wave energy, which results in the reduction of sediment transport capacity, and causes the accumulation of sediment in sheltered area forming a tombolo. If the retention of sediments is considerable, the tombolo can stop the long shore transport and the behaviour becomes analogous to groins (Figure 6.14-3).

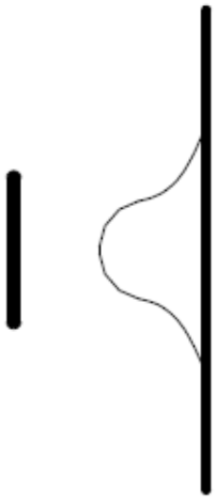


**Figure 6.14-4: Schematic representation of a detached breakwater**

*Advantages:*

- The surf wave occurs away from the coast and therefore decreases the incident wave energy on shoreline;
- Allows the accumulation of sediment in sheltered area;
- Possibility of using different materials (geotextiles or other) which may contribute to reduce the coast of the intervention;
- Detached breakwater is used to mitigate partially and permanently wave energy capacity, being effective on stabilizing beaches;
- Possibility of use these structures for other purposes in order to contribute to financially support of the intervention (energy or surfing).

*Disadvantages:*

- The aesthetic value of the beach is can be reduced (emerged breakwaters);
- Costs of building and maintaining superior to structures located along the shore;
- Anticipates erosion down drift of the intervention, due the accumulation of sediment in the detached breakwater sheltered area;
- Can generate currents in sheltered areas that jeopardize the safety of users of the beach;
- There is no practical use of these structures in the Portuguese Atlantic coast.

**Palisades and walkways**

The placement of the palisades stops wind sediment transport, and therefore encourages the natural process of retaining sand dunes. It also serves to protect from trampling, since it limits the areas of access to beaches. The placement of walkways to make access to the beaches allows maintaining the integrity of the dune system, not weakening this natural defence.

*Advantages:*

- Intervention of minimally invasive nature that promotes the development of the dune system;
- Creating walkways for access to beaches protecting the dunes;
- Possibility of using materials and integrated environmental solutions;
- Economic solution.

*Disadvantages:*

- These structures not resist to maritime action, so, when used in vulnerable dune systems and subject to direct wave action, are destroyed, which often occurs during storm periods.

**Step 4 - Data collection**

**What are the costs and what are the benefits of the alternative adaptation options?**

Based on Perreira (2014), three main coastal erosion adaptation pathway scenarios are considered (Table 6.14-1): Scenario 1 entails artificial beach nourishments of urban fronts with a large volume of sediments in combination with minor hard intervention measures; Scenario 2 entails artificial beach nourishments of urban fronts with a medium volume of sediments in combination with moderate hard intervention measures; and Scenario 3 entails artificial beach nourishments of urban fronts with a small volume of sediments in combination with major hard intervention measures. Within each of these scenarios, three variants are considered: Variant A where artificial beach nourishments take place on a yearly basis; Variant B where artificial beach nourishments take place once every two years; and Variant C where artificial beach nourishments take place once every five years. The artificial beach nourishments will lead to a temporary accretion of urban front beach areas – size depending on the volume of sediments deposited (Table 6.14-1).

**Table 6.14-1: Scenario characteristics**

| Intervention | Scenario 1 | Scenario 2 | Scenario 3 | Costs |
|---|---|---|---|---|
| Dune reinforcement | +1m along 14km<br>= $+70.0*10^3$ $m^3$ | +2m along 14km<br>= $+350.0*10^3$ $m^3$ | +3.5m along 14km<br>= $+1\ 050*10^3$ $m^3$ | Inv.: 6 €/m3<br>Maint.: - |
| Seawall Labrego | 100m | 200m | 300m | Inv.: 8 000 €/m<br>Maint.: 500 €/m |
| Palisades | 14km | 14km | 14km | Inv.: 150 €/m<br>Maint.: 15 €/m |
| Artificial nourishment | $+1.0*10^6$ $m^3$/yr | $+0.5*10^6$ $m^3$/yr | $+0.1*10^6$ $m^3$/yr | Inv.: 5 €/m3<br>Maint.: - |
| Breakwater Vagueira | - | - | 700m | Inv.: 15 000 €/m<br>Maint.: 1 500 €/m |
| Overtopping Vagueira | 1x/20yrs | 1x/4yrs | - | 3.9 m€/event |
| Beach: - Barra<br>- Costa Nova<br>- Vagueira | +250m - +438m<br>+200m - +350m<br>+285m - +499m | +167m - +292m<br>+133m - +233m<br>+190m - +333m | + 95m - +167m<br>+ 76m - +133m<br>+109m - +190m | |

Source: Based on Perreira (2014)

Investment (Inv.) and maintenance (Maint.) costs and intervals vary between the considered soft and hard intervention measures, and are summarized in Tab. 2. Note that the maintenance intervals for hard intervention measures vary between scenario variants: 10 years for Variant A, 5 years for Variant B and 2 years for Variant C. Overtopping takes place once every 2 years across the Vagueira urban front (Perreira and Coelho, 2010), with an average affected area of 14 ha and inundation level of 5 cm. The value of the “Urban fabric” land cover class is differentiated for real estate structure (1,134 EUR/m2; INE, 2010) and content (250 EUR/m2; Fidelidade, 2015) values. Parameter values for the depth-damage-functions (DDFs; Eq. 2) are estimated at a = 38.7 and b = -8.7 for structure ($R^2$ = 0.90) and at a = 51.4 and b = -10.8 for contents ($R^2$ = 0.96) (based on Davis and Skaggs, 1992). Resulting flooding costs associated with overtopping across the Vagueira urban front are estimated at 3.9 per event. The land cover class values (in/ha/yr.) adopted in this study are given in Tab. 3, including reference to the source of information. Land cover class values are largest for artificialized areas (up to 573 k EUR/ha/yr. for “Urban fabric”) and considerable for some of the natural areas (up to 123/ha/yr. for “Coastal wetlands” and “Coastal waters”). No values were obtained for the land cover classes “Mine, dump and construction sites” and “Artificial, non-agricultural vegetated areas”.

**Table 6.14-2: Coastal land cover class values (in 2010 EUR/ha/yr.)**

| Coastal land cover class | Value | Source |
|---|---|---|
| Urban fabric | 572 936 | INE (2010) |
| Industry, commercial and transport | 297 461 | INE (2010); INIR (2011); CapitolFax (2010) |
| Mine, dump and construction sites | - | - |
| Artificial, non-agricultural vegetated areas | - | - |
| Arable land | 525 | Roebeling et al. (2012) |
| Permanent crops | 525 | Roebeling et al. (2012) |
| Heterogeneous agricultural areas | 525 | Roebeling et al. (2012) |
| Forests | 1 917 | De Groot et al. (2012) |
| Scrub and/or herbaceous vegetation | 1 010 | De Groot et al. (2012) |
| Dunes | 18 394 | De Groot et al. (2012) |
| Beaches | 18 394 | De Groot et al. (2012) |
| Open spaces with little vegetation | 1 010 | De Groot et al. (2012) |
| Inland wetlands | 16 336 | De Groot et al. (2012) |
| Coastal wetlands | 123 302 | De Groot et al. (2012) |
| Coastal waters | 123 302 | De Groot et al. (2012) |
| Ocean | 312 | De Groot et al. (2012) |

For the calculation of benefits and costs, constant 2010 prices (2010EUR) are used. The fixed time discount rate is set at 3%, while the declining discount rate varies between 3.0% and 1.9% (3.0% in year 2010, 2.5% by 2020, 2.2% by 2030, 2.0% by 2040 and 1.9% by 2050).

Relative to the shoreline in 2010, the baseline shoreline evolution is based on a constant wave climate and considering the currently installed coastal defence interventions. In the early 70’s, the Costa Nova - Vagueira coastal stretch could be considered a true groin field due to the existence of 11 groins (Magalhães et al., 2004). This has, however, changed and currently there are a total of 9 groins and 4 seawalls in the study area. The resulting land cover losses or, alternatively, advances of the “Ocean” (see Table 6.14-3), are used as a basis for comparison of the coastal erosion adaptation pathway scenarios. For the baseline situation, i.e. without additional intervention measures (Perreira, 2014), land cover is consistently lost over time – thereby noting that the rate of loss reduces over time (see Table 6.14-3). Coastal erosion processes in the case study area are expected to lead to a net land loss of 32.6 ha (-1.2%) over the next 40 years. The land cover classes “Dunes”, “Forests” and “Urban fabric” are affected most (-38.4 ha, -7.7 ha and -1.1 ha, respectively), while “Beaches” are expected to increase (+16.3 ha) due to the sediment released by these former areas. The impacts on artificial surfaces (“Urban fabric” and “Industry, commercial and transport”) are small in terms of area (-1.1 ha and -0.4 ha, respectively).

**Table 6.14-3: Baseline land cover evolution between 2010 and 2050 in ha**

| Coastal land cover class | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|
| Urban fabric | 247.9 | 247.9 | 247.1 | 246.9 | 246.7 |
| Industry, commercial and transport | 113.2 | 113.2 | 113.0 | 112.9 | 112.9 |
| Mine, dump and construction sites | 13.1 | 13.1 | 13.1 | 13.1 | 13.1 |
| Artificial, non-agricultural vegetated areas | 37.0 | 37.0 | 37.0 | 37.0 | 37.0 |
| Arable land | 672.5 | 672.5 | 672.2 | 672.2 | 672.1 |
| Permanent crops | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Heterogeneous agricultural areas | 9.6 | 9.6 | 9.6 | 9.6 | 9.6 |
| Forests | 1045.9 | 1045.9 | 1040.5 | 1039.1 | 1038.2 |
| Scrub and/or herbaceous vegetation | 131.9 | 131.9 | 131.3 | 131.2 | 131.1 |
| Dunes | 176.1 | 157.0 | 148.8 | 141.9 | 137.7 |
| Beaches | 264.7 | 270.8 | 276.3 | 279.2 | 281.0 |
| Open spaces with little vegetation | 6.3 | 6.3 | 6.3 | 6.3 | 6.3 |
| Inland wetlands | 7.2 | 7.2 | 7.2 | 7.2 | 7.2 |
| Coastal wetlands | 248.9 | 248.9 | 248.9 | 248.9 | 248.9 |
| Coastal waters | 354.3 | 354.3 | 354.3 | 354.3 | 354.3 |
| Ocean | 2530.2 | 2543.2 | 2553.3 | 2559.2 | 2562.8 |
| Total | 5859.7 | 5859.7 | 5859.7 | 5859.7 | 5859.7 |

Total economic values for the case study area equal about 262 m EUR per year in 2010. In contrast with the land cover distribution, “Urban fabric” and “Industry, commercial and transport” account for more than 67% of the total coastal economic values (~142/yr. and ~34/yr., respectively), followed by 28% for “Coastal waters” and “Coastal wetlands” (~44/yr. and ~31/yr., respectively). The land cover classes “Beaches” and “Dunes”, on the other hand, provide together only 3% of the total economic values (about ~5/yr. and ~3/yr., respectively).

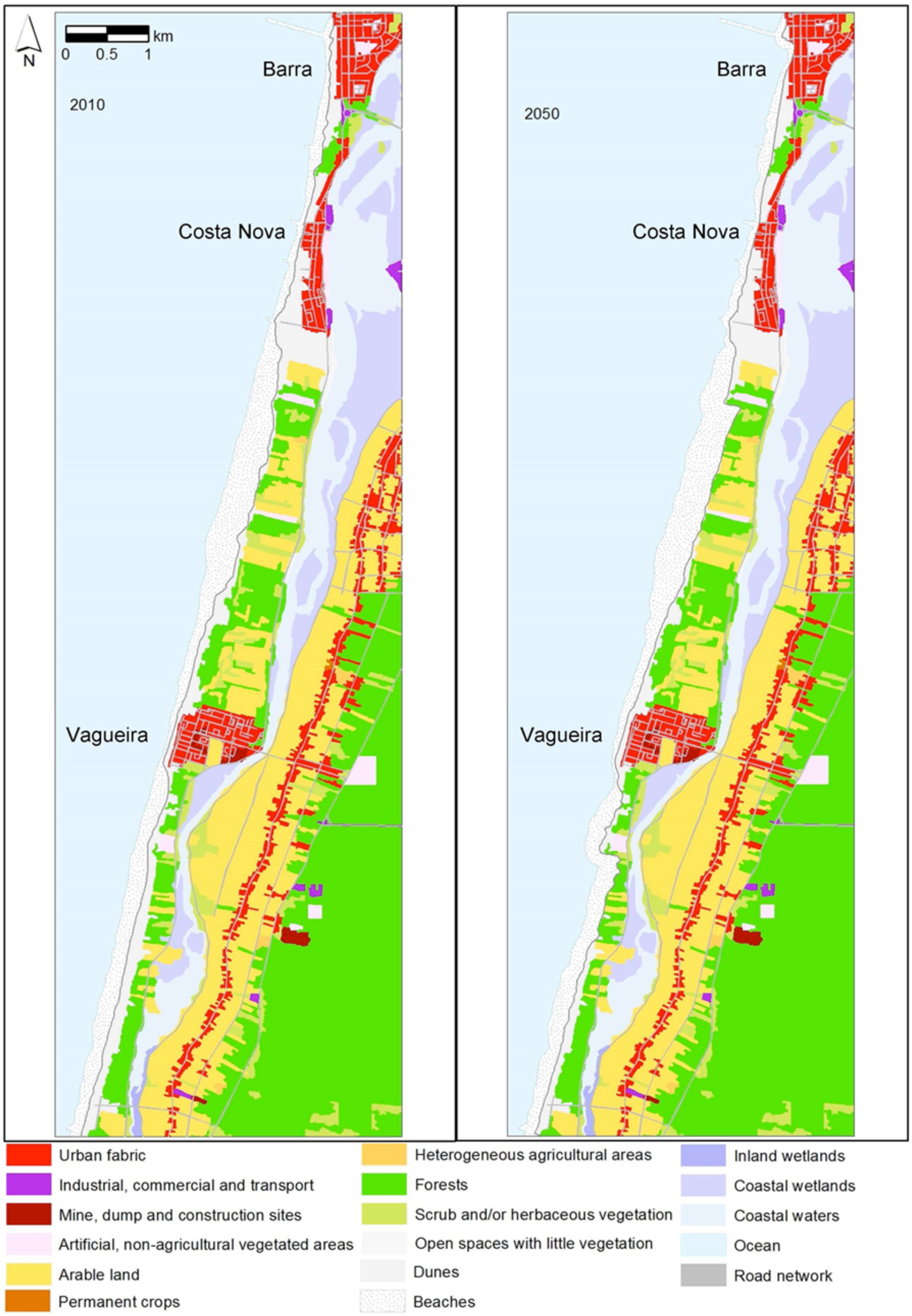



**Figure 6.14-5: Land cover in 2010 and 2050 for the case study area Barra-Areão**

**Step 5 – Evaluation and Prioritization**

**What is the ranking order of alternative adaptation options (measures, bundles of measures or pathways)?**

The cost-benefit analysis is performed relative to the baseline situation. Costs relate to the establishment and maintenance of intervention measures, while benefits relate to the built and natural capital rental values from the land cover classes not (yet) lost as well as flooding events avoided due to the establishment of these interventions. Scenario simulation results show that neither Scenario 1 nor Scenario 2 provides positive returns to investment (Table 6.14-4 and Table 6.14-5). Although these scenarios completely halt land cover losses and reduce flooding risk, investment and maintenance costs are up to almost 70% larger than the expected benefits. Scenario 1 is the least attractive, due to the high recurrent investment costs associated with the large artificial beach nourishments of urban fronts.

**Table 6.14-4: Scenario simulation results considering fixed discount rates (3%)**

| Scenario | Costs (2010 m€) | Benefits (2010 m€) | NPV (2010 m€) | BCR (ratio) |
|---|---|---|---|---|
| Scen.1A | 124.4 | 80.4 | -44.0 | 0.65 |
| Scen.1B | 127.7 | 83.9 | -43.8 | 0.66 |
| Scen.1C | 137.7 | 82.4 | -55.2 | 0.60 |
| Scen.2A | 67.4 | 53.3 | -14.1 | 0.79 |
| Scen.2B | 69.1 | 55.7 | -13.4 | 0.81 |
| Scen.2C | 74.1 | 54.7 | -19.3 | 0.74 |
| Scen.3A | 49.4 | 67.6 | 18.2 | 1.37 |
| Scen.3B | 49.7 | 68.9 | 19.2 | 1.39 |
| Scen.3C | 50.7 | 68.4 | 17.6 | 1.35 |

Scenario 3 provides positive returns to investment (Table 6.14-4 and Table 6.14-5) as it halts land cover losses and eliminates flooding risk, while entailing lowest recurrent investment (beach nourishments) and maintenance (hard intervention measures) costs. Across all scenarios, Variant B performs best – indicating largest benefits are obtained when artificial beach nourishments take place once every two years

**Table 6.14-5: Scenario simulation results considering declining discount rates (3% - 1.9%)**

| Scenario | Costs (2010 m€) | Benefits (2010 m€) | NPV (2010 m€) | BCR (ratio) |
|---|---|---|---|---|
| Scen.1A | 142.9 | 94.1 | -48.8 | 0.66 |
| Scen.1B | 146.6 | 98.2 | -48.4 | 0.67 |
| Scen.1C | 157.8 | 96.4 | -61.4 | 0.61 |
| Scen.2A | 76.9 | 62.9 | -14.0 | 0.82 |
| Scen.2B | 78.7 | 65.6 | -13.1 | 0.83 |
| Scen.2C | 84.3 | 64.4 | -19.9 | 0.76 |
| Scen.3A | 53.9 | 79.8 | 26.0 | 1.48 |
| Scen.3B | 54.3 | 81.4 | 27.1 | 1.50 |
| Scen.3C | 55.4 | 80.7 | 25.3 | 1.46 |

Comparison of the results obtained with the fixed (Table 6.14-4) and declining (Table 6.14-5) discount rates, and shows that returns to investment are slightly higher when a declining discount rate is applied. This is due to the fact that largest benefits are obtained towards the end of the planning horizon, when artificialized land cover classes are affected. Performance indicators are hardly affected by declining discount rates in Scenario 1, as this scenario is characterized by high recurrent costs as well as benefits – boosting almost equally present value costs (+15%) and benefits (+17%). Scenario 3 benefits most from declining discount rates as it is characterized by lowest recurrent costs and considerable benefits – boosting in particular present value benefits (+18%) and, to a minor extent, present value costs (+9%). Again, scenario Variant B performs best across all scenarios.

**Sensitivity analysis**

Sensitivity analyses are performed for variations in costs (Table 6.14-6), benefits (Table 6.14-7) and discount rates (Table 6.14-8), thereby considering declining discount rates (3.0% - 1.9%).

**Table 6.14-6: Sensitivity analysis on costs considering declining discount rates (3% - 1.9%)**

| Scenario | Costs -10% | | Costs 0% | | Costs +10% | | Costs +50% | |
|---|---|---|---|---|---|---|---|---|
| | NPV (2010m€) | BCR | NPV (2010m€) | BCR | NPV (2010m€) | BCR | NPV (2010m€) | BCR |
| Scen.1A | -34.5 | 0.73 | -48.8 | 0.66 | -63.1 | 0.60 | -120.2 | 0.44 |
| Scen.1B | -33.8 | 0.74 | -48.4 | 0.67 | -63.1 | 0.61 | -121.7 | 0.45 |
| Scen.1C | -45.7 | 0.68 | -61.4 | 0.61 | -77.2 | 0.56 | -140.3 | 0.41 |
| Scen.2A | -6.3 | 0.91 | -14.0 | 0.82 | -21.6 | 0.74 | -52.4 | 0.55 |
| Scen.2B | -5.2 | 0.93 | -13.1 | 0.83 | -21.0 | 0.76 | -52.4 | 0.56 |
| Scen.2C | -11.5 | 0.85 | -19.9 | 0.76 | -28.3 | 0.69 | -62.1 | 0.51 |
| Scen.3A | 31.3 | 1.65 | 26.0 | 1.48 | 20.6 | 1.35 | -1.0 | 0.99 |
| Scen.3B | 32.6 | 1.67 | 27.1 | 1.50 | 21.7 | 1.36 | 0.0 | 1.00 |
| Scen.3C | 30.9 | 1.62 | 25.3 | 1.46 | 19.8 | 1.32 | -2.4 | 0.97 |

Decreasing costs (-10%) lead, self-evidently, to improved performance indicators for all scenarios (11% increase in BCR; Table 6.14-6). A 10% reduction in costs is, however, not sufficient to provoke positive returns to investment for Scenario 1 and 2. Effects on Scenario 1 are small because recurrent investment costs remain large as compared to the associated benefits. For Scenario 2, however, returns to investment are approaching the minimum required levels (NPV >0; BCR > 1). The opposite holds for an increase in costs (+10% and +50%), thereby noting that a 50% increase in costs would put the viability of Scenario 3 in question. Note, again, that scenario Variant B performs best in all cases.

**Table 6.14-7: Sensitivity analysis on benefits considering declining discount rates (3% - 1.9%)**

| Scenario | Benefits -10% | | Benefits 0% | | Benefits +10% | |
|---|---|---|---|---|---|---|
| | NPV (2010 m€) | BCR | NPV (2010 m€) | BCR | NPV (2010 m€) | BCR |
| Scen.1A | -58.2 | 0.59 | -48.8 | 0.66 | -39.4 | 0.72 |
| Scen.1B | -58.2 | 0.60 | -48.4 | 0.67 | -38.6 | 0.74 |
| Scen.1C | -71.1 | 0.55 | -61.4 | 0.61 | -51.8 | 0.67 |
| Scen.2A | -20.2 | 0.74 | -14.0 | 0.82 | -7.7 | 0.90 |
| Scen.2B | -19.7 | 0.75 | -13.1 | 0.83 | -6.5 | 0.92 |
| Scen.2C | -26.3 | 0.69 | -19.9 | 0.76 | -13.5 | 0.84 |
| Scen.3A | 18.0 | 1.33 | 26.0 | 1.48 | 33.9 | 1.63 |
| Scen.3B | 19.0 | 1.35 | 27.1 | 1.50 | 35.3 | 1.65 |
| Scen.3C | 17.3 | 1.31 | 25.3 | 1.46 | 33.4 | 1.60 |

Finally, a reduction in declining discount rates (1.0% - 0.6%) leads to improved performance indicators for all scenarios (2% to 12% increase in BCR; Table 6.14-8). This reduction in declining discount rates is, however, not sufficient to provoke positive returns to investment for Scenario 1 and 2. Scenario 3 benefits most from reduced discount rates as it suffers least from the present value increase in recurrent investment and maintenance costs (lowest of all scenarios) while, equally, benefitting from the present value increase in recurrent benefits. The opposite reasoning holds for an increase in declining discount rates, thereby noting that performance indicators remain positive for Scenario 3. Again, scenario Variant B performs best in all cases.

**Table 6.14-8: Sensitivity analysis on declining discount rates**

| Scenario | *r* = 1.0% - 0.6% | | *r* = 3.0% - 1.9% | | *r* = 5.0% - 3.2% | |
|---|---|---|---|---|---|---|
| | NPV (2010 m€) | BCR | NPV (2010 m€) | BCR | NPV (2010 m€) | BCR |
| Scen.1A | -59.7 | 0.67 | -48.8 | 0.66 | -40.9 | 0.64 |
| Scen.1B | -58.9 | 0.69 | -48.4 | 0.67 | -40.9 | 0.65 |
| Scen.1C | -74.8 | 0.63 | -61.4 | 0.61 | -52.2 | 0.59 |
| Scen.2A | -14.2 | 0.85 | -14.0 | 0.82 | -13.6 | 0.78 |
| Scen.2B | -13.0 | 0.87 | -13.1 | 0.83 | -13.0 | 0.80 |
| Scen.2C | -21.4 | 0.80 | -19.9 | 0.76 | -18.9 | 0.73 |
| Scen.3A | 42.3 | 1.66 | 26.0 | 1.48 | 14.6 | 1.31 |
| Scen.3B | 43.8 | 1.68 | 27.1 | 1.50 | 15.5 | 1.33 |
| Scen.3C | 41.5 | 1.63 | 25.3 | 1.46 | 14.0 | 1.29 |

The objective of this study is to assess the economic viability of the three main coastal erosion adaptation pathways identified for the for the Barra-Vagueira coastal stretch. These scenarios halt land cover losses and reduce flooding risk, and entail (see Perreira, 2014):

- Scenario 1: artificial beach nourishments of urban fronts with a large volume of sediments in combination with minor hard intervention measures;
- Scenario 2: artificial beach nourishments of urban fronts with a medium volume of sediments in combination with moderate hard intervention measures; and
- Scenario 3: artificial beach nourishments of urban fronts with a small volume of sediments in combination with major hard intervention measures.

The developed and applied methodology combines a coastal erosion and flood damage assessment approach (Merz et al., 2010) as well as a benefits transfer approach (Brouwer, 2000), as to analyse the costs and benefits of these the three main coastal erosion adaptation pathways (following Roebeling et al., 2011).

Total economic values for the case study area equal about 262 m EUR per year in 2010, with “Urban fabric” and “Industry, commercial and transport” accounting for 67% and “Coastal waters” and “Coastal wetlands” accounting for 23% of the total coastal economic values. Baseline results show that land cover is expected to be consistently lost over time without additional intervention measures – with erosion processes expected to lead to a net land loss of 32.6 ha over the next 40 years. Expected losses in economic values for the case study area are estimated at 1.4 m EUR per year by 2050.

Scenario simulation results show that neither Scenario 1 nor Scenario 2 is expected to provide positive returns to investment. Although these scenarios completely halt land cover losses and reduce flooding risk, investment and maintenance costs are up to almost 70% larger than the expected benefits. Scenario 3 is expected to provide positive returns to investment as it halts land cover losses and eliminates flooding risk, while entailing lowest recurrent investment and maintenance costs. Hence, scenarios involving large artificial beach nourishments and minor hard intervention measures are not attractive from an economic perspective, due to the high recurrent investment costs associated with the beach nourishments; scenarios combining small artificial beach nourishments and major hard intervention measures are attractive from an economic perspective, as they entail lowest recurrent costs while equally providing considerable benefits. Across all scenarios, largest benefits are obtained when artificial beach nourishments take place once every two years.

The sensitivity analyses, on discount rates as well as cost and benefit variations, show that these results are consistent. Decreasing costs and discount rates as well as increasing benefits lead to improved performance indicators for all scenarios. A 10% reduction in costs or increase in benefits is, however, not sufficient to provoke positive returns to investment for Scenario 1 and 2, although returns to investment are approaching the minimum required levels for Scenario 2. Cost overruns of 50% would put the viability of Scenario 3 in question. Largest benefits continue to be obtained when artificial beach nourishments take place once every two years. Some caveats remain. First, it can be argued that the maintenance costs of hard intervention measures increase for scenarios with sediment deficits. Second, it can be argued that flooding costs for non-artificialized land cover classes should be taken into account. Finally, it can be argued that the study area should be extended to South as to account for benefits from increased sediment delivery, from artificial beach nourishments, to these areas.

## 6.15 Cascais

Filipe Moreira Alves, FFCUL

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

According to the National Risk Assessment of 2014, a document issued by the National Civil Protection office under the "*Risk Assessment and Mapping Guidelines for Disaster Management*" emitted by the European Commission (document SEC (2010) 1626 final, of 21.12.2010), one of Portugal's highest vulnerabilities in its territory concerns the water sector, namely the issue of water scarcity south from Tagus River and the important issue of urban flooding, namely in the great Lisbon and Porto area (see images under, both from 2014). The fore mentioned vulnerabilities are both expected to increase as overall annual precipitation is expected to reduce by at least 15% until the end of the century in the southern part of the country and peak precipitation events will increase by 20% to 30 % according to the new RCP scenarios produced by IPMA[72]. Other empirical studies also show that the number of flood events in Portugal has been increasing sharply both in number of occurrences and intensity. These intense precipitation events, leading to peak flood events have also been identified by the EEA as a major source of economic damage and human loss – between 1998 and 2009 1120 died due to floods and economic losses exceeded 52 bn EUR (EEA, 2012). In Portugal, flood events occur annually in the Tagus River Basin, but two flood events stand-out in our recent history: the 1967 flood event in Lisbon with 700 deaths and the 1983 in Lisboa and Cascais with 10 deaths. Regarding all flood events, those with higher damage curves are short-intense-peak flood events (Barredo, 2006; Ramos & Reis, 2001).

As one can see in Figure 6.15-2 Cascais is a highly vulnerable municipality to floods not only due to its high urbanization ratio and development but also due to its morphological and geographical specific characteristics (Gaspar 2013). It is important to mention that Cascais, as all municipalities in Portugal, according to Portuguese law – Decreto-lei Nº 364/98 and Decreto-Lei nº 115/2010 – are obliged to have a Chart of Flooding Areas as well as to create measures to mitigate and adapt the risk of flooding within its territory, a crucial document for the city's urban planning and development as well as for the delimitation of its Ecologic Reserve Area (REN). It is also important to mention that REN has a mandatory implementation and already foresees a number of restrictions for flood prone areas - Decreto-Lei nº166/2008 Artigo 20º and Decreto-Lei nº239/2012 Artigo 20º - namely, the prohibition to: a) allotment operations; b) Urbanization and construction projects c) Roads and other accesses; d) Digging and embankment; e) Destruction of natural ecosystems or the natural existent environment, except for normal agricultural practices and fire prevention measures regarding forest cleaning.

Cascais has had flood maps since 1998, where 16 water streams have been studied and monitored, 8 of which are of particular importance: Ribeiras dos Mochos; Ribeira das Vinhas; Ribeira da Cadaveira; Ribeira de Bicesse; Ribeira de Manique; Ribeira das Marianas; Ribeira dos Sassoeiros; Ribeira do Arneiro. These water streams vary significantly in terms of lenght, size of the water catchment basin, urbanization ratios, flood risk and assets at stake, which also means that the adaptation strategies and pathways for each may differ.

Nevertheless, in our analysis we'll take a closer look at Ribeira das Vinhas as it is the only one for which there is available data for different adaptation measures and directly influences the flood risk in downtown Cascais.

Overall and according to the Cascais Civil Protection Risk Assessment Report (2013) the risk exposure to floods is relatively moderate for the Municipality (see Table 6.15-1). However, high-risk exposure[73] exists in certain areas, which are also areas with strong economic activity concentration as well as physical capital, namely historical

[72] https://www.ipma.pt/pt/oclima/servicos.clima/index.jsp?page=cenarios21.clima.xml&print=tru

[73] Exposure represents the values, which are present at the location where the floods can occur, such as: cultural heritage, Infrastructure, goods, agricultural fields or people (Merz et al., 2007). On another hand Susceptibility to floods should be seen as the propensity of an area to be affected by floods and is given by the territory intrinsic characteristics such has slope, geology, river network, and land use. Finally, the concept of vulnerability is also important to clarify. According to UNESCO-IHE Institue for Water Education, vulnerability to floods can be considered "as the extent of harm, which can be expected under certain conditions of exposure, susceptibility and resilience."

buildings. Only 0,5% of the resident population is considered to be in high-risk areas and 70% of all buildings have low to moderate risk exposure.

**Table 6.15-1: Risk exposure to flood events (2013)**

| Risk exposure to floods | Inexistent | Low | Moderate | High |
|---|---|---|---|---|
| Population (inhabitants) | 62.180 | 137.292 | 6.148 | 859 |
| Buildings (nrº) | 12.151 | 29.959 | 1.310 | 204 |
| Environment (Hectares) | 2.748 | 1.077 | 76 | 34 |

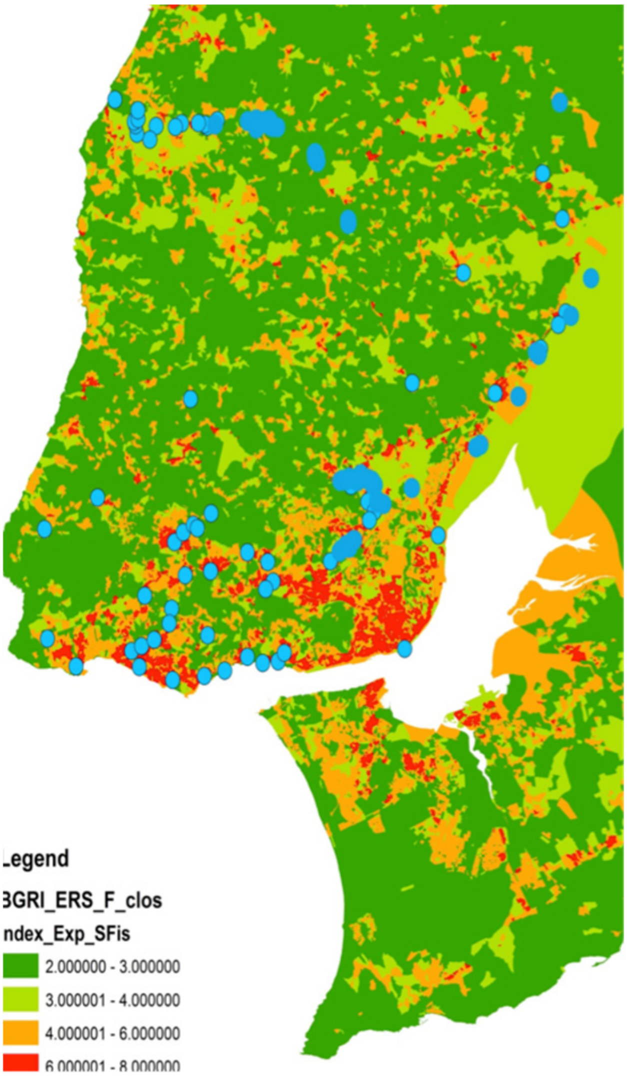



**Figure 6.15-1: Flood vulnerability Index for the Lisbon area**
Note: Blue dots represent flood events.

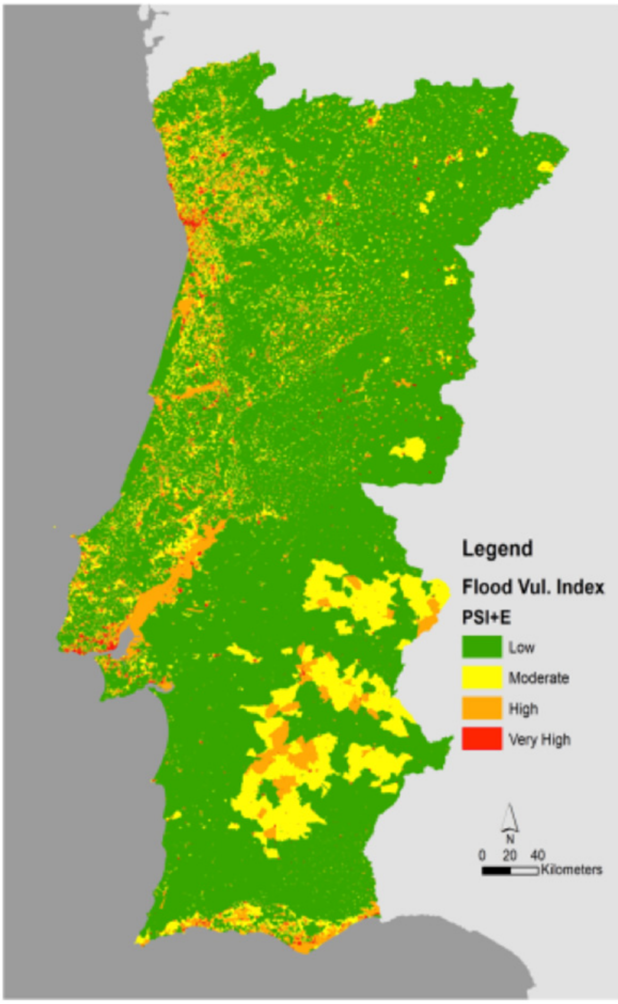



**Figure 6.15-2: Flood vulnerability index for Portugal**

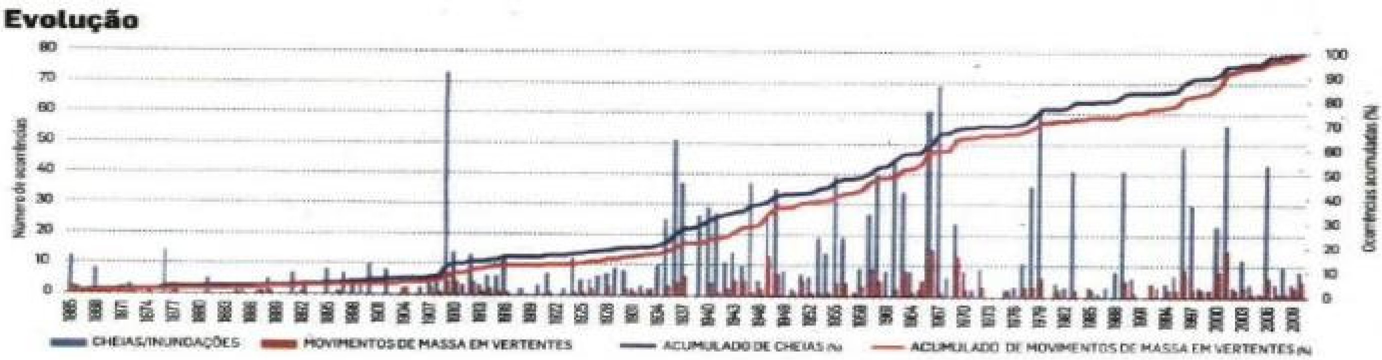



**Figure 6.15-3: Evolution of flood events and mass movements in Portugal in the last 100 years**

Recent studies from empirical data retrieved from private insurance companies also show growing damage costs curves for floods events in Portugal (see figures below). From this data we can see that extreme events can cost almost 1MEUR per event and that in recent years there has been (in average) more than 500.000 EUR per year just in private claims to insurance companies. Matching this data with climatic data we are able to construct and elaborate damage curves (see Figure 6.15-5) for different return periods. However, longer scales are needed for better calibration and validation of the appropriate function to use.

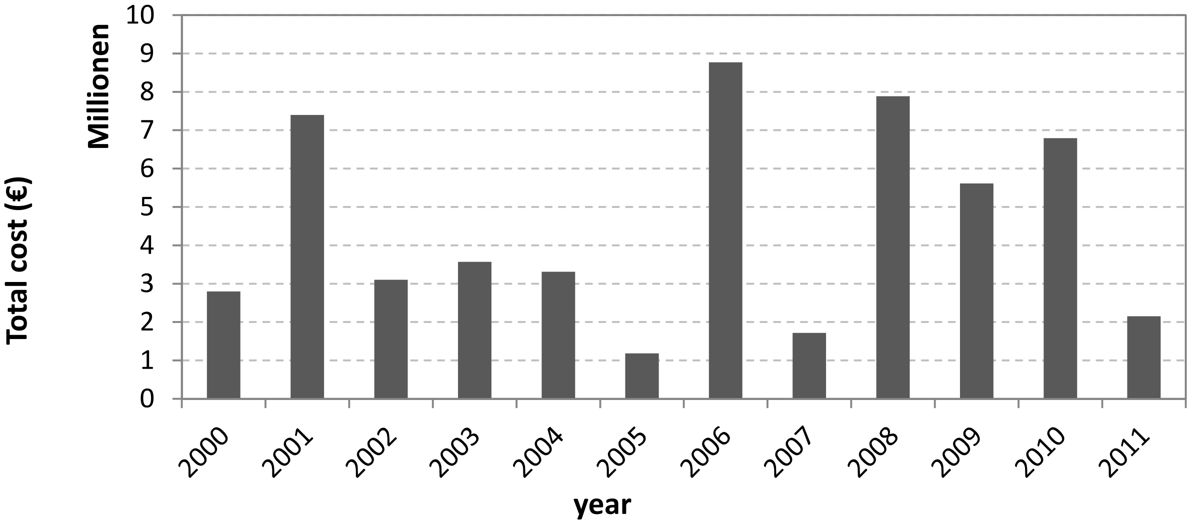



**Figure 6.15-4: Annual national private claims to insurances by private households and businesses**[74]

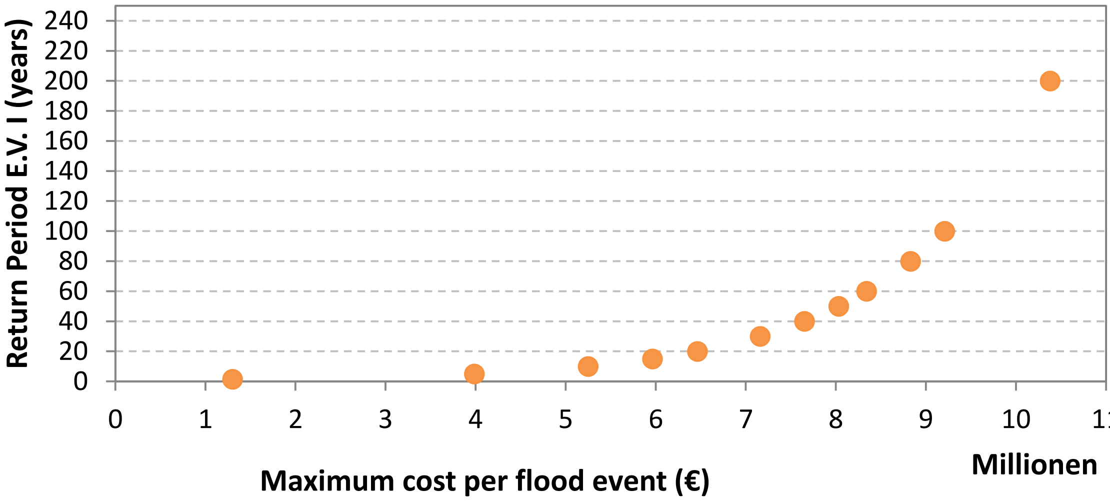



**Figure 6.15-5: Damage function for future costs due to flood events according to different return periods**[75]

As for the Municipality of Cascais and in the period between 2000 and 2011 there were just over 1MEUR in private claims to insurance companies being that 40% of that value occurred in a single event in 2008 in two parishes. Data regarding the costs of such events upon public property for this period is either unavailable or scattered among different budgets, different budget lines, emergency lines etc., making it nearly impossible to trace back. See Figure 6.15-6 for the annual private costs due to flooding in Cascais.

[74] APS, 2014. Cartas de Inundação e Risco em cenários de alterações climáticas. ISBN: 978-972-98847-5-7
[75] Ibidem (5)

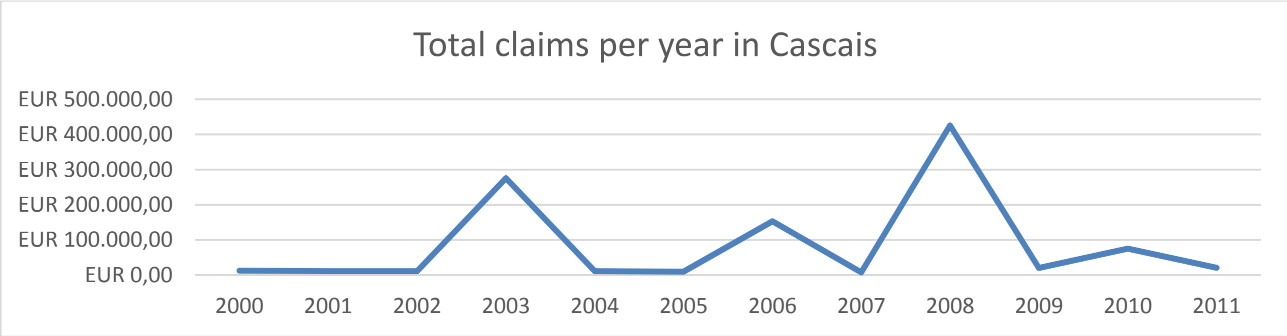



**Figure 6.15-6: Annual private claims to insurances by private households and businesses in Cascais 2000-2011**[76]

Still regarding our risk assessment it is fundamental to point out that for the municipality of Cascais the flood risk is present in high urban density areas with numerous assets and strong economic activity namely touristic areas. While overlapping the asset map of Cascais regarding historical buildings and heritage with the flood risk maps for a 100 year return flood we find evidence of strong vulnerability of key assets in Cascais to floods (see Figure 6.15-8, Figure 6.15-9, Figure 6.15-10, Figure 6.15-11).

A general overview of Cascais streams and the crucial water streams is presented below, as well as a detail modelling of Ribeira das Vinhas - regarding flood risk and vulnerable area for a return period of T = 100 years according to a 2010 study, updated recently (2013)[77]. Table 6.15-2 also shows empirical data retrieved from the Pisão meteorological station, allowing us to estimate the maximum daily precipitation for a 100-year flood.

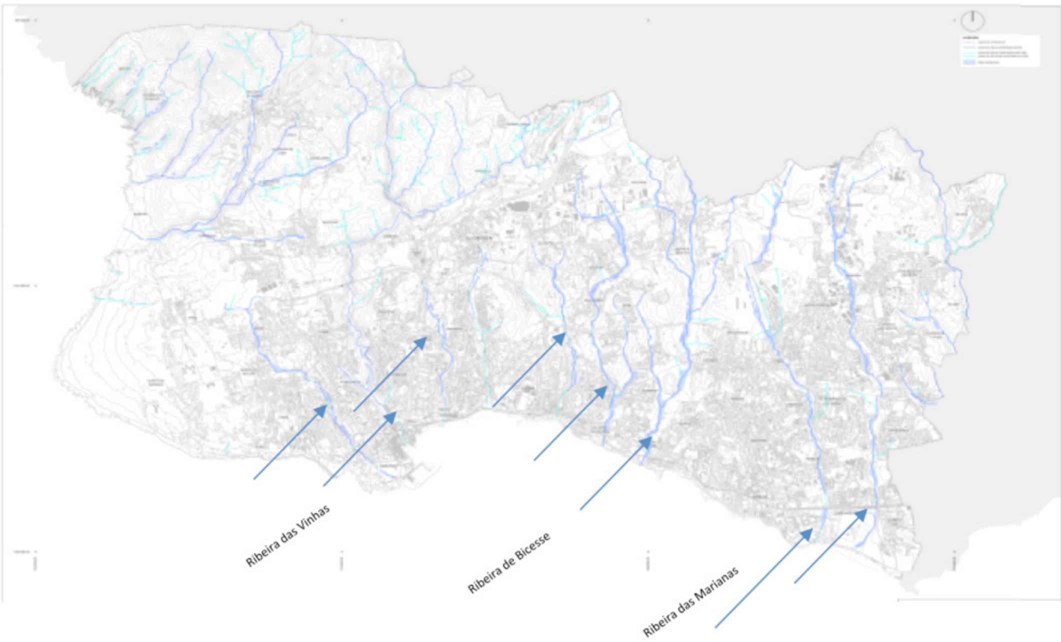



**Figure 6.15-7: General overview of Cascais streams highlighting 8 crucial ones**

[76] APS, 2014. Cartas de Inundação e Risco em cenários de alterações climáticas. ISBN: 978-972-98847-5-7

[77] Cardoso, Alexandra et Quaresma, Manuel dos Santos (2010), Elaboração da Carta de Áreas Inundáveis para o Concelho de Cascais para o período de Retorno de 100 anos, Relatório Final, Hidroprojecto

**Table 6.15-2: Daily max annual precipitation in Pisão 1979-2000**

| Data | Daily max annual precipitation (mm) |
|---|---|
| 06-Oct-79 | 60 |
| 10-Apr-81 | 39,2 |
| 30-Dec-81 | 65 |
| 07-Nov-82 | 43 |
| **19-Nov-83** | **127,5** |
| 07-Feb-85 | 48 |
| 25-Feb-87 | 35 |
| 04-May-88 | 51 |
| 08-Apr-89 | 40 |
| 29-Apr-90 | 66,5 |
| 12-Fev-91 | 50 |
| 11-Oct-91 | 27 |
| 13-Mar-93 | 59,5 |
| 12-Oct-93 | 73,7 |
| 01-Nov-95 | 63,5 |
| 21-Dec-96 | 34,3 |
| 02-Nov-97 | 57 |
| 10-Mar-99 | 50 |
| 20-Oct-99 | 67,4 |
| 22-Nov-00 | 46 |

**Table 6.15-3**

| Return period | Precipitation height – x (mm) |
|---|---|
| 2 | 51,7 |
| 5 | 70,4 |
| 10 | 82,8 |
| 20 | 94,7 |
| 50 | 110,1 |
| **100** | **121,7** |
| 500 | 148,4 |

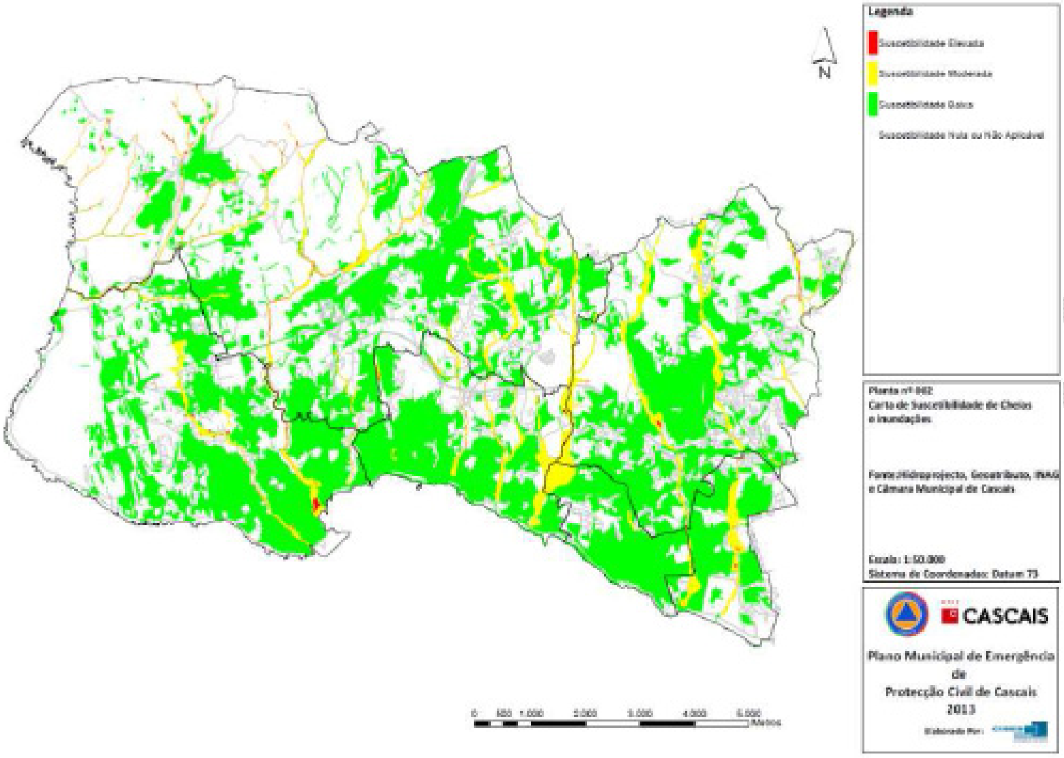



**Figure 6.15-8: Flood Susceptibility Chart of Cascais 2013**

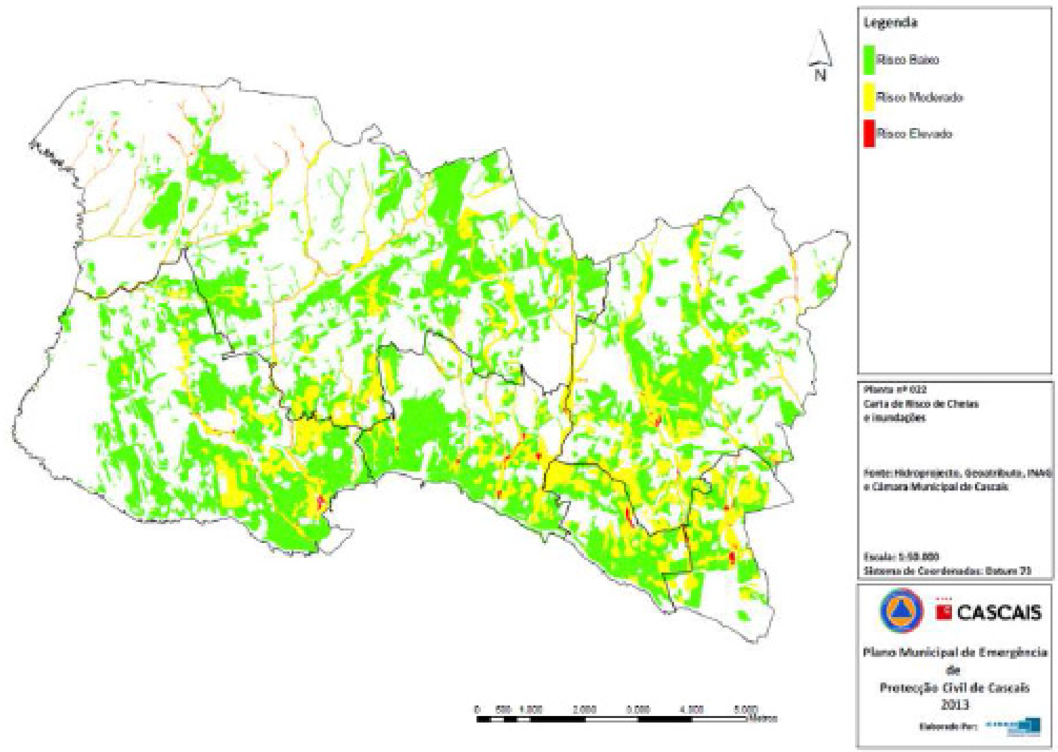



**Figure 6.15-9: Flood risk chart of Cascais 2013**

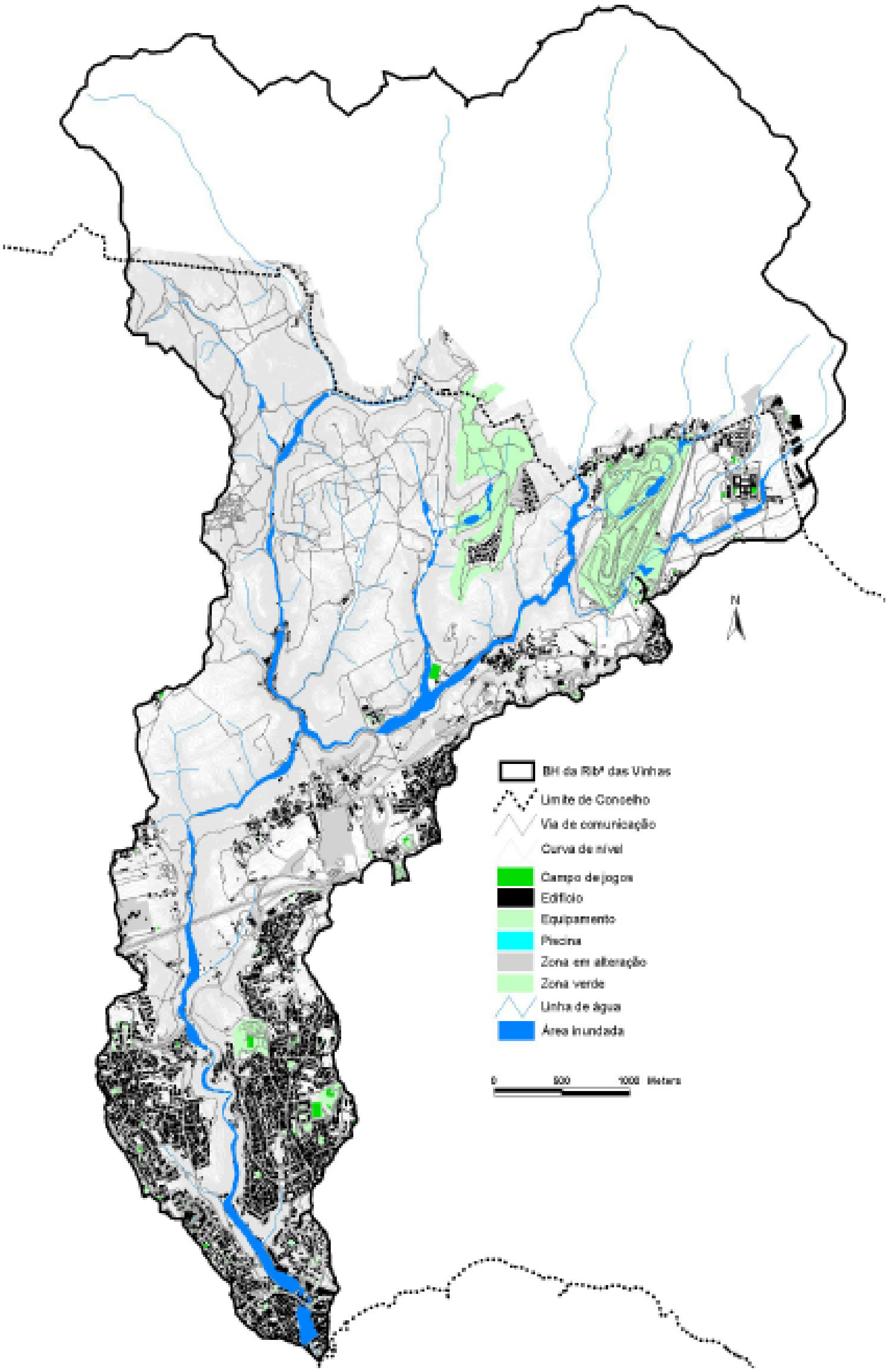



**Figure 6.15-10: T-100 Flood risk chart for Ribeira das Vinhas**

Our economic analysis will focus more specifically in Ribeira das Vinhas, which is a 9,4 km long stream with total of 26,2 km of hydro graphic basin, although only 14,5 km2 belongs to the Municipality of Cascais. Ribeira das Vinhas is born at 478 meters in the Sintra-Cascais Natural Park and flows to the sea in downtown Cascais with an average slope of 1,9%. Regarding our vulnerability analysis and the final proposal presented in Step 5 of this economic analysis it is fundamental to also assess for the Ribeira das Vinhas basin area the soil uses as well as the chart of slopes. Regarding Figure 6.15-12 we can see big differences in land uses from upstream to downstream as the urbanization rate grows dramatically in the lower basin, exactly where the most vulnerable flood areas are located (see Figure 6.15-11). It is also in this downtown areas where the most valued historical assets are located.

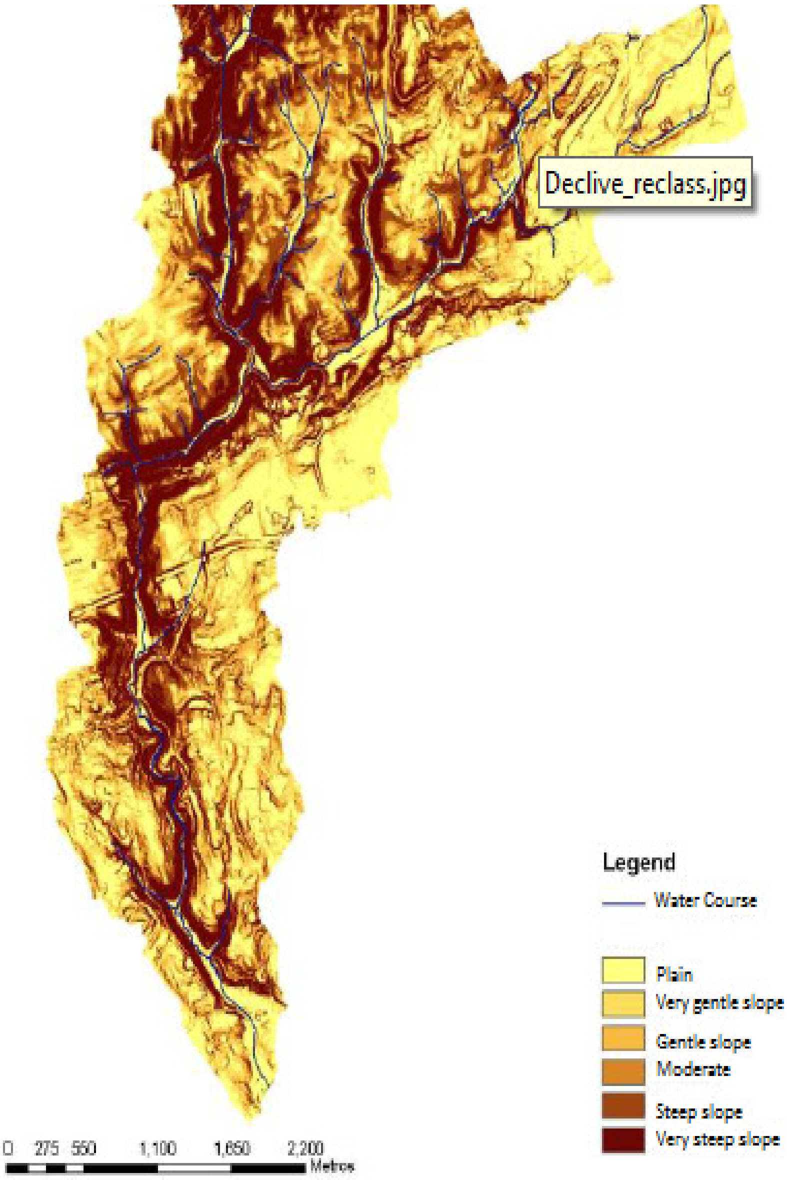



**Figure 6.15-11: Chart of slopes for Ribeira das Vinhas**

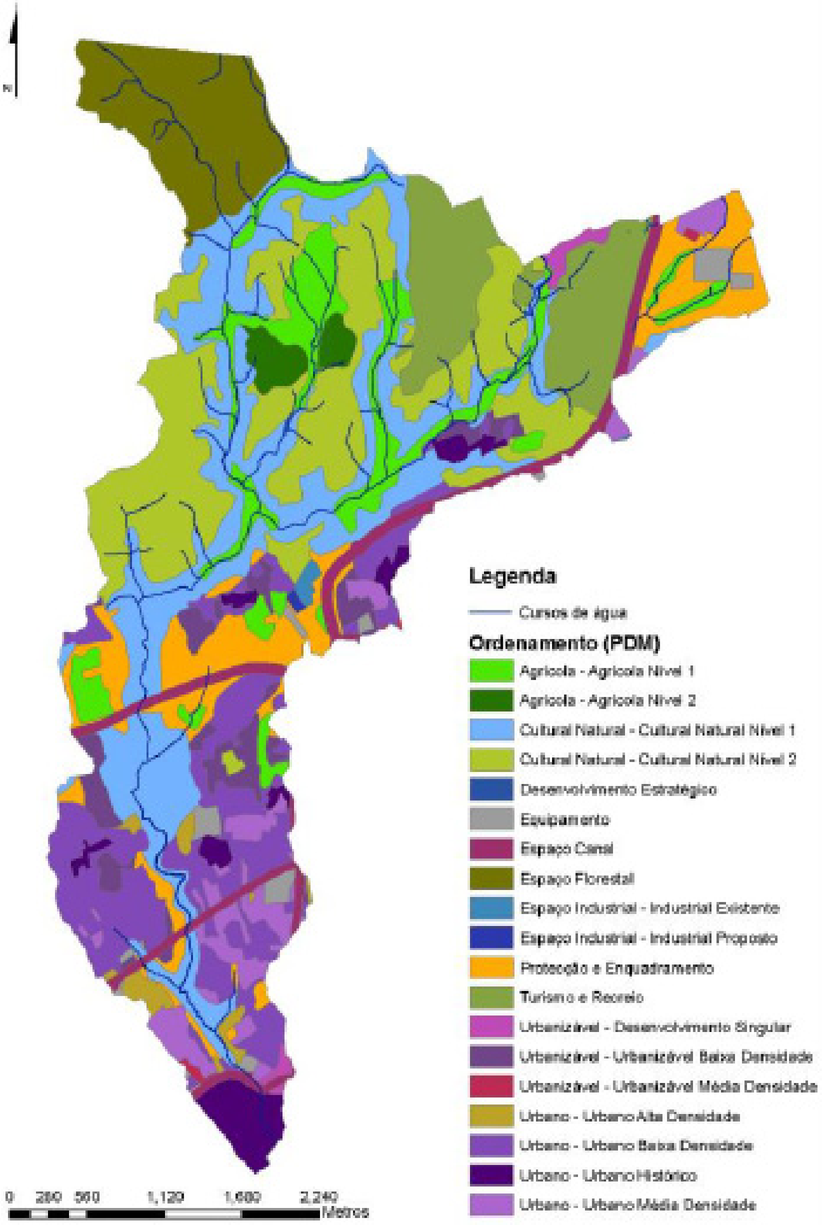



**Figure 6.15-12: Municipality planning and land uses chart**

Finally it is important to highlight that for the return period of T = 100 it is estimated a flood peak flow of 183m3/s, with a total tributary volume of 1597 Dam3, while the flow capacity is estimated at 33,9 m3/s.

Not only due to the regulatory demands but also due to the historical events that happened in Cascais related with floods (1967 and 1983), the Municipality has been developing a number of studies and interventions to address its vulnerabilities, namely through the design and implementation of the Cascais Ecologic Structure Plan which aims to pave the way for green corridors and other green adaption measures to be implemented. These measures include: restoring and connecting public gardens; increase in public gardens; restoring water streams; plantation of native trees and shrubs alongside water streams and in the green corridors.

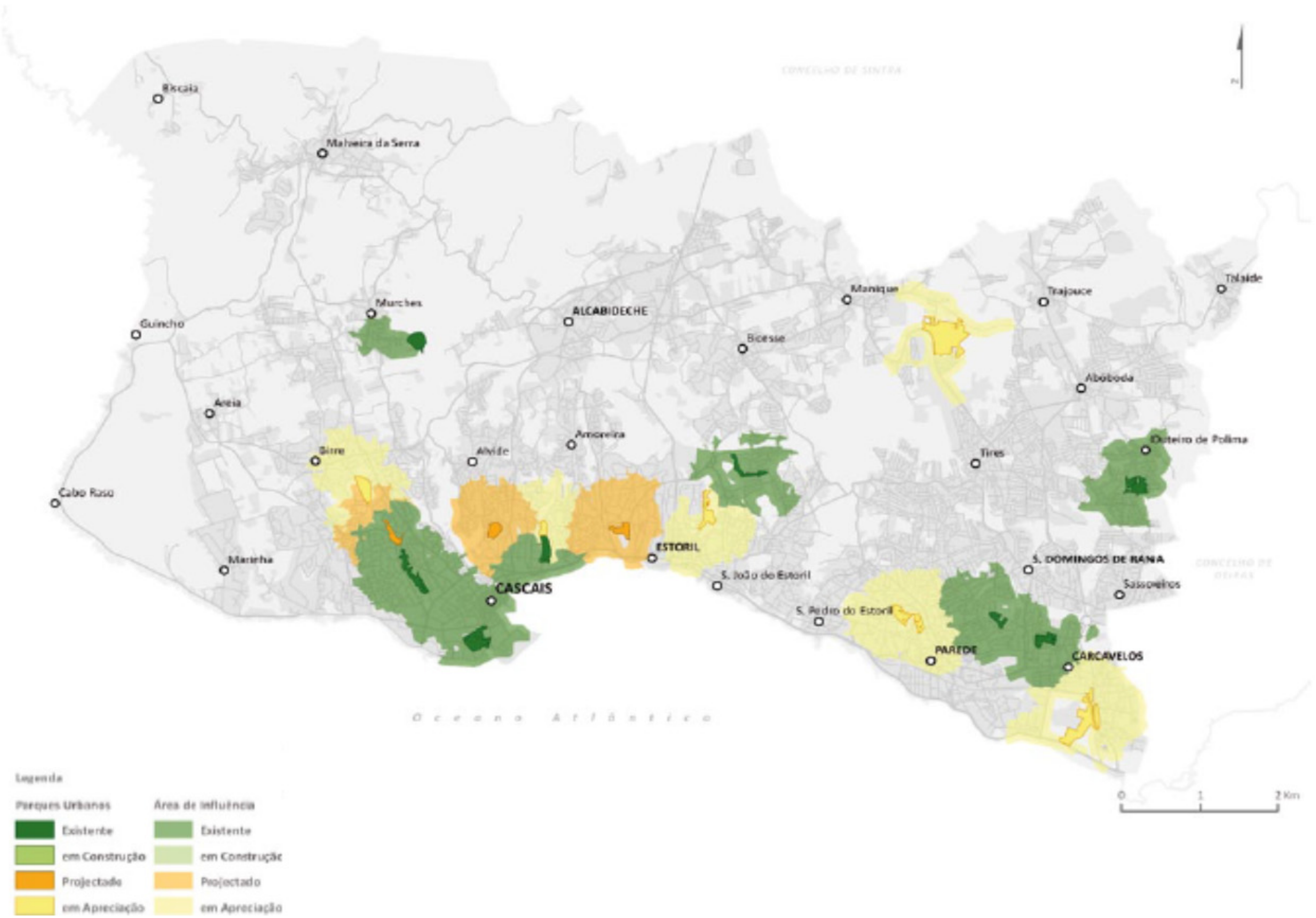



**Figure 6.15-13: Existing (green) and planned (yellow) green ecologic structures of Cascais (2008)**

However, most of the measures identified have seen little or no progress in recent years and even some drawbacks' have been reported regarding constructions and approved lots in flood prone areas or REN areas.

This will be further analysed in the next steps.

**Step 2 – Identification of Adaptation Measures**

Adaptation measures to flooding in cities according to the EEA Report No2/2012 'Urban Adaptation to Climate Change in Europe':

**Table 6.15-4: Adaptation measures to flooding in cities. Adapted from EEA 2/2012**

| Grey measures | Green measures | Soft measures |
|---|---|---|
| Flood proofing of new buildings | Avoid/remove impervious surfaces | Forecasting and early warning systems |
| Maintenance/upgrade of drainage system | Green infrastructure (parks, gardens, wetlands) | Awareness raising, capacity building |
| Temporary water storage in basins | Re-naturalization of rivers and wetlands | Strategic planning in river basins |
| Separated rainwater and sewage systems | | Flood risk management plans |
| Innovative design of buildings and areas such as elevated entrances, green roofs | | Taxes or incentives |
| Dams, flood defences | | Insurance of damages |

For our case study of Cascais, most of the above mentioned measures were already included in the PECAC 2010, while others, such as the Green roofs were only introduced in this revision of the Cascais Strategy. The following measures were – fully or partially – analysed during our research period:

- Green measures: Rainwater gardens; green corridors and the rehabilitation of Cascais streams;
- Grey measures: Separation of rainwater and waste water systems; rainwater harvesting; Water efficiency in distribution

Adaptation measure brief description:

A **Green roof, living roof or also ecoroof**, is any roof on an existing building, which contains soil and vegetation as its outermost layer. There are many different types of green roofs but they typically include a drainage layer, a root barrier, a soil mix, a vegetation layer and a waterproof membrane. The soil depth normally varies between 10 and 30 cm. However there can be implementations with deeper soils, even capable of sustaining trees and bushes – see Hundertwasser work – as well as thinner implementations (less than 20 cm), known as extensive green roofs (Sailor 2008).

A **Rain garden** is "a planted depression or a hole that allows rainwater runoff from impervious urban areas, like roofs, driveways, walkways, parking lots, and compacted lawn areas, the opportunity to be absorbed" (Bannerman 2003).

**Rainwater harvesting** is "a technology used for collecting and storing rainwater from rooftops, land surfaces or rock catchments using simple techniques such as natural and/or artificial ponds or reservoirs" (Helmreich et Horn, 2009).

The concept of **Green Infrastructure or ecologic structure** can be considered to compromise "all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales" (Tzoulas, 2007).

Green corridors and rehabilitation/re-naturing of streams

Re-naturing or rehabilitating a river or a stream means restoring its original structure and functions bringing it back as much as possible to the original natural state (water course) before human intervention/interference. This can be achieved by a number of different actions such as: giving the stream more room; letting the river/stream meander again; enlarging and flattening the stream banks; enhancing erosion control, replanting namely with native species; removing non-native species; allowing for more daylight to reach the stream.

The primary objective of the fore mentioned adaptation measures concerns Flood risk reduction and the protection of assets, however, both grey and green measures also carry important side objectives, namely: increase water storage and self-sufficiency in order to increase drought resilience; increased efficiency in water distribution and usage to decrease energy spending; increased resilience of natural systems and urban population to heat waves. These positive externalities are summarized below (see Figure 6.15-14), however extensive literature exist on the subject, namely regarding Life Cycle Analysis of green measures (See for example Flynn, 2011; Wong et all, 2003). It is important to highlight the matter of LCA when comparing for example Rainwater gardens versus green roofs as taking into consideration its positive and negative externalities from construction to end of cycle disposal some important conclusion arise, such as the significance of overall impacts which is much lower for a rainwater garden (see Figure 6.15-14).

| Benefit | Reduces Stormwater Runoff | | | | | | | | | | | Improves Community Livability | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Reduces Water Treatment Needs | Improves Water Quality | Reduces Grey Infrastructure Needs | Reduces Flooding | Increases Available Water Supply | Increases Groundwater Recharge | Reduces Salt Use | Reduces Energy Use | Improves Air Quality | Reduces Atmospheric $CO_2$ | Reduces Urban Heat Island | Improves Aesthetics | Increases Recreational Opportunity | Reduces Noise Pollution | Improves Community Cohesion | Urban Agriculture | Improves Habitat | Cultivates Public Education Opportunities |
| Practice | | | | | | | | | | $CO_2$ | | | | | | | | |
| Green Roofs | Yes | Yes | Yes | Yes | No | No | No | Yes | Yes | Yes | Yes | Yes | Maybe | Yes | Maybe | Maybe | Yes | Yes |
| Tree Planting | Yes | Yes | Yes | Yes | No | Maybe | No | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Maybe | Yes | Yes |
| Bioretention & Infiltration | Yes | Yes | Yes | Yes | Maybe | Maybe | No | No | Yes | Yes | Yes | Yes | Yes | Maybe | Maybe | No | Yes | Yes |
| Permeable Pavement | Yes | Yes | Yes | Yes | No | Maybe | Yes | Maybe | Yes | Yes | Yes | No | No | Yes | No | No | No | Yes |
| Water Harvesting | Yes | Yes | Yes | Yes | Yes | Maybe | No | Maybe | Maybe | Maybe | No | No | No | No | No | No | No | Yes |

Yes Maybe No

**Figure 6.15-14: Externalities of green adaptation measures (CNT, 2010)**

The externalities highlighted above represent a fundamental piece of the puzzle in any full costs and benefit analysis and their true accounting and internalization in the economic analysis is of paramount importance if any of these measures is to be economically justifiable in the short term. This is particularly relevant for big investments such as Green roofs and rainwater harvesting. In step 4 some data ranges are presented for key benefits of green measures.

Equally important and a *sine qua non* condition in any integrated economically sound analysis is to consider Life Cycle Analysis of the measures. Extensive literature already exists on the subject and although high uncertainty in data still asks for prudence, some values are shown in this report in order to contextualize and consider the relative perspective for some „green measures". Below a comparative analysis of the environmental impact of green roofs versus rainwater gardens in different 10 categories – such as contribution to Global warming, smog or air quality - is presented. In this figure 100% represents the estimated total life cycle impact of a 4.100 square meter of green roof. As we can see the overall life cycle impact for a rainwater garden is significantly lower than of a green roof.

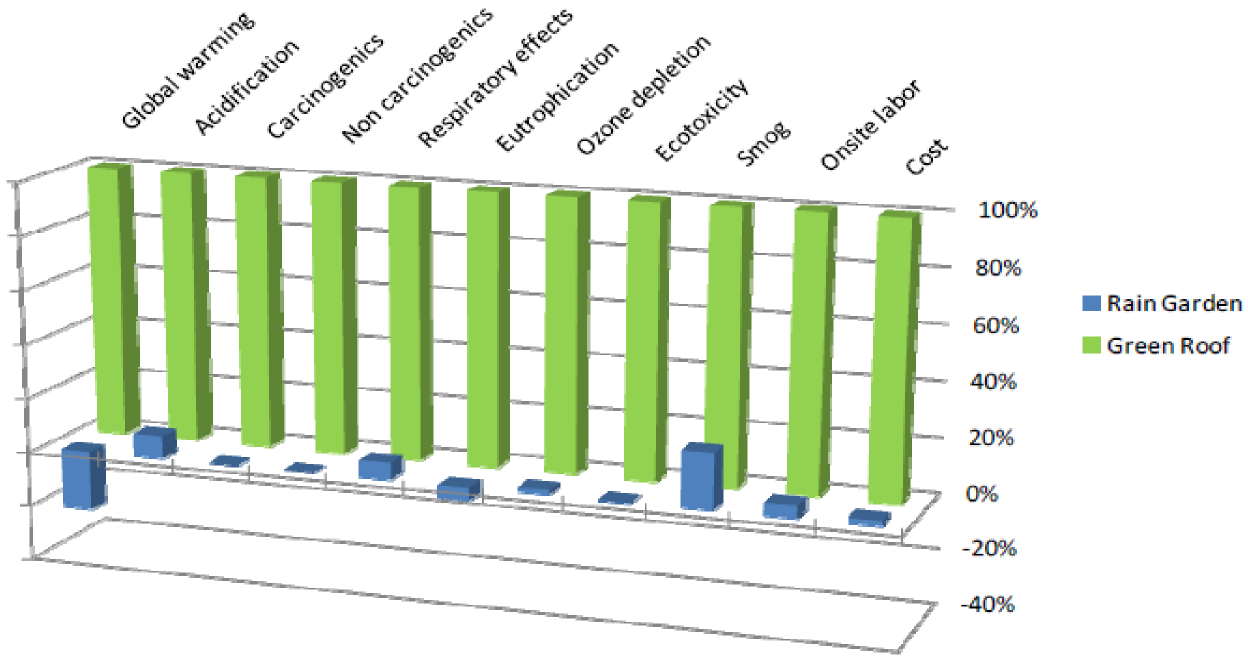



**Figure 6.15-15: Life Cycle Analysis of Rain garden versus Green roof**
Source: Lynn (2011)

In order to really assess the positive and negative externalities of each measure is also important to understand their primary objective regarding which variables from the equation under each measure acts upon, regarding water flow and consequently flood risk:

$$H = P - E - \Delta S_p - \Delta S_u - \Delta S - E_x + R$$

Equation 1: Water flow in cities[78]

$$H = P - \Delta S_p - \Delta S$$

Equation 2: Reduced version of water flow in cities

Most of the adaptation measures here considered impact upon specific variables related to surface water retention and storage as well as soil permeability. Other adaptation measures such as *wet flood proofing* or dry *flood proofing* were not looked upon in this analysis neither did such extreme measures as geo engineering (used on *P*, i.e., to lower the probability of flash floods).

[78] *H* = water flow; *P* = Precipitation; *R* = Water dump into the system by human activities; *E* = Evapotranspiration *Ex* = Water extraction from human activity ; $\Delta S_p$ = Variation in the surface water retention and storage $\Delta S_u$ = Variation in the subterranean reserves; $\Delta S$ = variation of water store in the soil (impermeability of the land)

Before dwelling deeper into our analysis of the adaptation measures it is important to highlight some remarks from our research process in Cascais during BASE:

**Table 6.15-5: Explanation adaptation measures in Cascais**

| Adaptation measure | Remarks |
|---|---|
| Green Roofs | Measure initially explored and suggested for deeper analysis but not considered a priority in the MCA by the local stakeholders neither by the official representatives of the Municipality due to high costs of implementation and lack of local knowledge/experiences. Mediterranean studies are briefly presented and referenced. |
| Rainwater gardens | Measure well received but not considered a priority by the stakeholders. A prospective study for 3 rainwater gardens and associated investment costs is also presented and is currently being proposed in the last Regional Spatial Strategy (PDM). |
| Green corridors and the re-naturing of Cascais streams | Measure that gathered wide consensus among local stakeholders and was considered a priority. A detailed study is presented. Was considered already in implementation by majority of the local stakeholders. |
| Rainwater catchment | Measure received good considerations by the local stakeholders in the MCA but was not considered a priority. Official representatives of the Municipality refused public investment on it but support private decentralized investments. Investment costs are presented based on the literature. |
| Separated rainwater and sewage systems | Measure already implemented in Cascais. The system is not optimal yet due to illegal ramifications and connections, which are being detected and act upon by Águas de Cascais. Although sub-optimal it was not considered a priority for adaptation as it concerns and impacts mainly private households with illegal system links. |
| Reduction of water losses in distribution | Measure already implemented in Cascais. Initially it was considered in the local stakeholders MCA as a priority but this was due to lack of information as Cascais reached in 2014 its economically optimal water losses level being a Portuguese benchmark case study. Investments were done by the Águas de Cascais from 2007 to 2014. |

For the case study of Cascais the Adaptation Pathways approach was not followed. Adaptation measures were clustered into sectors but not bundled. Most measures regarding flood risk reduction were clustered into the water sector besides Green Corridors, which joined the biodiversity cluster.

**Step 3 - Evaluation Criteria and Method**

In our economic analysis of urban flash flooding adaptations measures, within the research methodology and principles set for Cascais, three different but connected core methods were used: Multi-criteria Analysis; Participatory Benefit-Cost Analysis and Cost-effectiveness Analysis. They were complemented by stakeholder subjective prioritization as well as stakeholder investment allocation during the participatory workshops. All of this is presented below in section 3.4 of this report.

Participatory MCA was used in order to assess and filter several different adaptation measures by many different stakeholders in a resource-efficient manner according to 6 evaluation criteria's, all of which had been previously used in the PECAC 2010 process: Technical, Institutional and Social complexity of implementation; scale of Importance, urgency and no-regrets. Stakeholders, grouped in teams of 5 or 6 had to commonly agree upon a subjective ranking from 1 to 5.

Participatory Benefit-cost analysis was subsequently used in order to better assess the most relevant measure for Cascais, coming from the MCA, as well as signal future CEA and CBA regarding which are the most relevant economic, social and environmental impacts (positive and negative) of the measure.

Cost-effectiveness Analysis was later used to evaluate four alternative, and complementary, adaptation measures for flood adaptation in Ribeira das Vinhas.

Cost-benefit Analysis was not used neither considered for this specific case study due to:

1. Focus was on the use of participatory methodologies and development of new economic assessment tools, such as the PBCA;
2. Data on avoided damages (benefits) for flash flood adaptation measures was either scarce, unavailable or highly uncertain, namely for public infrastructure;
3. Priority objective was to compare several adaptation options, for which CEA is an optimal, efficient and cost-effective tool.

The methods presented regarding the economic appraisal of these different adaptation measures within our research methodology were introduced in three subsequent steps. These steps were not only designed according to the existing available information but mainly according to the principles of integration, participation, diversity and trans-versatility of knowledge as well as complementarity of available tools.

*Step 1*: PECAC 2.0 workshop where participants representing most of the Municipality departments as well as local crucial stakeholders for adaptation re-prioritize the TOP 15 adaptation measures and performed a willingness to invest exercise on 20 adaptation measures previous selected and agreed upon - Each decision-maker had a 1MEUR to invest in climate change adaptation over a period of 3 years (Table 6-15-7). As one can see for the re-prioritization it is important to highlight that water efficiency and rainwater harvest replaced reduction of water pollution in the Top 5 as these were considered mostly implemented or already in implementation and that more than half of the measures are in the water sector (see Table 6.15-6). Rainwater harvesting was highlighted, which was the measures for which the willingness to invest was higher, while the rehabilitation of Cascais streams and rainwater gardens sits in the middle of the table and Green Corridors goes well down to 15/20.

*Step 2*: PECAC 2.1 workshops (namely Water and Biodiversity) where participants representing expert stakeholders from this clusters performed an MCA analysis and a PBCA on the most relevant adaptation measures (see Table 6.15-8, Table 6.15-9, Table 6.15-10). It is important to highlight that on average most adaptation measures were considered to have good social acceptability and a higher technical complexity for implementation than institutional complexity. Most measures were considered urgent, however not all were equally considered important for Cascais.

*Step 3*: Results from the PBCA where followed upon, crystalized and presented to the local decision-makers for feedback and comments.

Positive externalities are shown above in Step 2. As for specific measures such as green corridors, positive and negative properties are highlighted in the PBCA Matrix, which was filled by local key decision-makers and stakeholders. The issue of 'Job creation', which was considered to have a potential high economic short-term impact by the stakeholders was considered low in a deeper analysis as only 2 to 4 new job posts were foreseen. As for negative environmental impacts, in the case study presented in step 4 they were considered to be residual. Investments are also presented in step 4.

As for comparability between measures (for CEA of CBA) the most important impact is flood risk reduction, which can be measured by the amount of cubic meters of water stored and prevented from flowing into flood prone areas. The common unit is litre of water retained/stored per EUR invested. This measure can be translated into monetary values when effectiveness can be calculated in detail and with high confidence levels.

**The Participatory Benefit-Cost Analysis**

The **Participatory Benefit-Cost Analysis** (PBCA) is an economic appraisal tool which has been developed and tested by the Center for Climate Impact, Modelling and Adaptation (CCIAM), from the University of Lisbon, under FP 7 Project BASE – Bottom-up Adaptation Strategies for Europe - in order to assess through participatory methodologies the costs and benefits of different adaptation measures of the Strategic Plan for Climate Change of Cascais (PECAC). It is a simple-to-use, resource efficient, solutions focused, pro-active, deliberative process. The PBCA aims to combine the advantages and strengths of multi-criteria analysis with the rationality of Cost-benefit Analysis (CBA), thereby evolving from the simplicity of the Simplified Participatory Cost-Benefit Analysis (SPCBA) as proposed by the

Climate Resilience Framework – Training Kits (3rd series) – to deliver an all-in-one procedure for action-researchers working in climate adaptation.

PBCA can be defined as a hybrid methodology of economic project appraisal as it is composed of heterogeneous sources and diverse elements, combining interpersonal deliberation and quantitative methodologies to produce both depth and breadth in valuation and appraisal processes.

The PBCA Methodology has 5 different steps which can and should be completed in approximately one hour by groups of diverse stakeholders. The methodological steps are presented at the beginning by a session facilitator, which cannot be also a group focalizer. The objective of the session is also presented at the beginning, clarifying that the purpose "is not to calculate the "right" decision, but no help improve the understanding for decisions involving risks, multiple criteria, and multiple interests."(Bell et al, 2003: 2) as Michelle Bell, Benjamin Hobbs and Hugh Ellis have argued for participatory MCDM. The PBCA has 5 fundamental steps:

**Step 1:** Organize participating stakeholders into mixed groups of [3min-9máx; 5 is optimal], where each group is given one Adaptation Measure/Project to assess and one focalizer. It is extremely important to guarantee heterogeneity in the constitution of the groups, so as to foster rich debates from multiple perspectives.

**Step 2:** Each group is given the PBCA Matrix and 30 min to fill it according to sub-step 1 - name the impacts – sub-step 2 - value each impact according to the given scale – sub-step 3 - calculate ratios.

**Step 3:** The session facilitator presents the concept of discounting and offers different alternatives for the participants' consideration. Doubts are clarified.

**Step 4:** The participants are given 15 min to debate the discount rate to apply in each group. Group Discussion on which Discount factor to apply and net final value calculation

**Step 5**: Each group selects a representative group speaker, which presents in 1-3 minutes the final net value, the discount rate choice and the overall discussion regarding the costs and benefits of the adaptation measure under scrutiny.

**Table 6.15-6: Top 15 Prioritization of adaptation measures (2010 & 2013)**

| Rank 2010 | Rank 2013 | PECAC Top 15 2010 | PECAC TOP 15_2013_ NEW PRIORITIES | SECTOR |
|---|---|---|---|---|
| 1 | **3** | Fire Prevention and Fight Plan | Awareness raising and Training of local stakeholders | **Education; Training;** |
| 2 | **10** | Rehabilitation of Cascais streams and water galleries | Water efficiency programs | **WATER** |
| 3 | **4** | Improve water use and reduce waste (ex: public gardens watering) | Fire Prevention and Fight Plan | |
| 4 | **13** | Reduction in occasional pollution points of water bodies | Improve water use and reduce waste (ex: public gardens watering) | **WATER** |
| 5 | **12** | Eliminate water pollution focal points | Rainwater harvest and supply | **WATER** |
| 6 | **1** | Awareness raising and Training of local stakeholders | Re-florestation of the Sintra-Cascais Park with native species | Biodiversity |
| 7 | **7** | Reduction in water losses in distribution | Reduction in water losses in distribution | **WATER** |
| 8 | **1** | Water efficiency programs | Coastal erosion protection and barriers | Coastal Erosion |
| 9 | **11** | Production and promotion of local products | New urban forests | Biodiversity |
| 10 | **13** | Prohibit new constructions next to cliffs | Rehabilitation of Cascais streams and water galleries | **WATER** |
| 11 | **9** | Coastal erosion protection and barriers | Production and promotion of local products | Local development |
| 12 | **8** | New urban forests | Reduction in continuous pollution points of water bodies | **WATER** |
| 13 | **5** | Rainwater harvest and supply | Eliminate water pollution focal points | **WATER** |
| 14 | **6** | Reforestation of the Sintra-Cascais Park with native species | Reduction in occasional pollution points of water bodies | **WATER** |
| 15 | **12** | Reduction in continuous pollution points of water bodies | Prohibit new constructions next to cliffs | Coastal erosion |

**Table 6.15-7: Average willingness to pay in adaptation measures taking into consideration a 1 m EUR yearly budget from 2014 to 2017 by 20 decision-makers**

| DG | Medida | 2014 | 2015 | 2016 | SOMA | % |
|---|---|---|---|---|---|---|
| 1 | **Rainwater harvest** | 105.500,0 | 78.000,0 | 78.000,0 | 261.500,0 | 9,98% |
| 2 | Sustainable School | 75.250,0 | 69.000,0 | 67.750,0 | 212.000,0 | 8,09% |
| 3 | Fire prevention and fight Plan | 65.000,0 | 67.750,0 | 59.000,0 | 191.750,0 | 7,32% |
| 4 | Natural Capital Management Plan | 59.250,0 | 59.000,0 | 71.750,0 | 190.000,0 | 7,25% |
| 5 | Reduction in water losses in distribution | 60.750,0 | 73.875,0 | 42.500,0 | 177.125,0 | 6,76% |
| 6 | Coastal erosion protection | 34.500,0 | 66.500,0 | 75.250,0 | 176.250,0 | 6,73% |
| 7 | Awareness and Training of stakeholders | 59.250,0 | 51.875,0 | 54.625,0 | 165.750,0 | 6,33% |
| 8 | Water and soil integrated management plans | 67.000,0 | 37.250,0 | 50.250,0 | 154.500,0 | 5,90% |
| 9 | Rehabilitation of Cascais streams and water galleries | 54.250,0 | 38.000,0 | 51.750,0 | 144.000,0 | 5,50% |
| 10 | Improve water use and reduce losses (ex: public garden watering) | 51.500,0 | 43.750,0 | 31.625,0 | 126.875,0 | 4,84% |
| 11 | **Rainwater gardens** | 41.250,0 | 55.750,0 | 28.250,0 | 125.250,0 | 4,78% |
| 12 | New urban forests | 37.500,0 | 34.000,0 | 38.500,0 | 110.000,0 | 4,20% |
| 13 | Reforestation of the Sintra-Cascais Park with native species | 35.000,0 | 36.250,0 | 35.500,0 | 106.750,0 | 4,07% |
| 14 | Production and Promotion of local products | 16.750,0 | 27.400,0 | 42.900,0 | 87.050,0 | 3,32% |
| 15 | **Green corridors** | 22.500,0 | 20.000,0 | 37.500,0 | 80.000,0 | 3,05% |
| 16 | Water efficiency programs | 34.750,0 | 23.250,0 | 13.250,0 | 71.250,0 | 2,72% |
| 17 | Eliminate water bodies pollution | 24.000,0 | 22.250,0 | 24.750,0 | 71.000,0 | 2,71% |
| 18 | Reduce pollutants discharges in water bodies | 14.600,0 | 22.500,0 | 29.000,0 | 66.100,0 | 2,52% |
| 18 | Water saving legislation in construction | 24.250,0 | 18.250,0 | 18.250,0 | 60.750,0 | 2,32% |
| 20 | Rainwater retention landscapes | 22.500,0 | 10.000,0 | 10.000,0 | 42.500,0 | 1,62% |
| | | | | | 2.620.400,0 | 100,00% |

**Table 6.15-8: Participatory Multi-criteria analysis in the biodiversity cluster workshop (results from Group A - 6 participants)**

| Cluster of measures – Water | Complexity of implementation (1 = High complexity; 5 = Low complexity) | | | | Relevance for Cascais (1 = Low; 5 = High) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Technical | Institutional | Social | TOTAL | Importance | Urgency | No-regrets | TOTAL | C*R |
| Water efficiency programs | 3 | 4 | 5 | **12** | 4 | 3 | 4 | **11** | **132** |
| Reduce water losses in distribution | 1 | 4 | 5 | **10** | 5 | 4 | 5 | **14** | **140** |
| Rainwater harvest | 2 | 2 | 5 | **9** | 2 | 1 | 2 | **5** | **45** |
| Rainwater gardens | 3 | 4 | 5 | 12 | 3 | 5 | 4 | **12** | **144** |
| Legislation for water saving codes in buildings | 5 | 5 | 5 | **15** | 2 | 2 | 2 | **6** | **90** |
| Saving water awareness campaigns | 5 | 5 | 3 | **13** | 4 | 3 | 3 | **10** | **130** |
| Rehabilitation of Cascais streams | 3 | 4 | 5 | **12** | 4 | 4 | 5 | **13** | **156** |
| Eliminate water pollution | 1 | 3 | 5 | **9** | 5 | 5 | 5 | **15** | **135** |

**Table 6.15-9: Participatory Multi-criteria analysis in the biodiversity cluster workshop (results from Group B - 5 participants)**

| Cluster of measures - Water | Complexity of implementation (1 = High complexity; 5 = Low complexity) | | | | Relevance for Cascais (1 = Low; 5 = High) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Technical | Institutional | Social | TOTAL | Importance | Urgency | No-regrets | TOTAL | C*R |
| Water efficiency programs | 3 | 3 | 2 | **8** | 5 | 5 | 5 | **15** | **120** |
| Reduce water losses in distribution | 3 | 3 | 5 | **11** | 5 | 5 | 4 | **14** | **154** |
| Rainwater harvest | 3 | 2 | 5 | **10** | 4 | 3 | 3 | **10** | **100** |
| Rainwater gardens | 4 | 2 | 5 | **11** | 3 | 1 | 3 | **7** | **77** |
| Legislation for water saving codes in buildings | 2 | 2 | 4 | **8** | 2 | 2 | 2 | **6** | **48** |
| Saving water awareness campaigns | 5 | 4 | 5 | **14** | 5 | 5 | 5 | **15** | **210** |
| Rehabilitation of Cascais streams | 2 | 2 | 5 | **9** | 3 | 3 | 4 | **10** | **90** |
| Eliminate water pollution | 3 | 4 | 2 | **9** | 5 | 5 | 4 | **14** | **126** |

**Table 6.15-10: Adaptation measure green corridor**

| | ENV | | | SOCIAL | | | ECONOMIC | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Effect Description | Short-term (2014/6) | Long-term (2050) | Effect Description | Short-term (2014/6) | Long-term (2050) | Effect Description | Short-term (2014/6) | Long-term (2050) | Short-term (2014/6) | Long-term (2050) |
| | Biodiversity hubs and channels | 1 | 4 | Shadow, heat-relief spaces | 1 | 3 | Real-estate valorisation | 1 | 4 | | |
| **BENEFITS** | Flood control; Erosion control | 1 | 2 | Meeting point | 1 | 2 | Job creation | 4 | 2 | **4,5** | **8,5** |
| | | **1** | **3** | | **1** | **2,5** | | **2,5** | **3** | | |
| | Negative impacts in fauna dynamics | 3 | 1 | Social resistance due to traffic changes | 4 | 1 | Investment | 5 | 1 | | |
| **COSTS** | - | | | Social resistance due to biodiversity increase | 2 | 1 | Maintenance | 2 | 3 | **9,5** | **4** |
| | | **3** | **1** | | **3** | **1** | | **3,5** | **2** | | |
| Rácio B/C | | **0,67** | **3** | | **0,17** | **2,5** | | **0,71** | **1,5** | **0,47** | **2,13** |
| | | | | | | | **FINAL NET PRESENT VALUE** | | | **1,7624859** | |

**Table 6.15-11: Sensitivity analysis on PBCA results from adaptation measures**

| Adaptation measure | CB Short term | CB Long term | Discount rate | Final present value (original, 2013-2020) | Final present value (original 2013-2050) | Final present value (3,5% 2020) | Final present value (3,5% 2050) |
|---|---|---|---|---|---|---|---|
| Green corridors | 0.5 | 2.25 | -1% | 1.445 | 1.8653875 | 1.13425 | 0.575125 |
| Reforestation of the Sintra-Cascais Natural Park | 0.8 | 6.5 | -5% | 4.755 | 20.998175 | 2.9545 | 1.33925 |
| Eliminate water pollution points | 2 | 2.42 | 1% | 2.14 | 1.84579 | 1.95106 | 1.34969 |
| Raising awareness in households regarding good sanitation practices | 2.25 | 3.5 | 1% | 2.7 | 2.34825 | 2.5005 | 1.63075 |
| Legislation towards bioclimatic construction norms | 5.25 | 4.5 | 1% | 4.74 | 4.19775 | 4.3935 | 3.27525 |
| Awareness raising campaigns for heat waves and heat stress | 1.25 | 2.2 | 1% | 1.68 | 1.3939 | 1.4896 | 0.9429 |

**Step 4 - Data collection Conclusion and insights for urban adaptation**

Setting up an evaluation criteria and method is directly at the crossroads between data availability and the research methodology itself. Regarding data availability here's a short summary:

**Table 6.15-12: Data availability for key adaptation measures implementation in Cascais**

| Adaptation measure | Costs | Benefits | Others reports and documents |
|---|---|---|---|
| Green roofs | Literature review on costs; High ranges; High level of uncertainty; | Literature review on benefits; High level of uncertainty. | Research gap for Portugal. |
| Rain gardens | Existing concrete studies from FCT/CMC on 3 rainwater gardens for Ribeira das Vinhas. | Avoided damages based on private claims to insurances; | Literature review with many examples for Mediterranean climate. |
| Green corridors | Existing studies and budget needs from CMC | High uncertainty based on difficulty to assess real effectiveness of measures; | Ecologic Structure of Cascais Plan; PDM Revision; Project Oxygen |
| Rainwater harvest | Literature review on costs; Low ranges and low uncertainty. | Literature review on benefits; Low level of uncertainty. | Case study benchmark of Barcelona; |

**Green roofs**

As mentioned before, the data regarding Green roofs varies significantly in the literature, both for costs and benefits as we can see in the figure below. We've used average approximations in order to evaluate the expected ranges, however specific values cannot be taken for a CBA as the uncertainty is so high.

**Table 6.15-13: Summary of costs for green roof systems from various sources (Schulze et Tröltzsch 2012)**

| | Additional installation costs in EUR/m2 | Additional maintenance costs in EUR/m2 |
|---|---|---|
| Mann 2005 | 5 – 14 | 0.30 |
| Acks 2006 | 8.57 – 214.44 | -0.34 – 9.86 |
| Clark et al. 2007 | 47.13 | No info |
| Carter & Keeler 2007 | 54.83 | 0 |
| City of Portland 2008 | 42.29 | 0.18 |

Also, one has to consider that in order to perform a cost-benefit analysis for a green roofs installation hard data needs with high resolution are demanded, namely for energy demand reductions, air quality improvements as well as real estate price valuation. Figure 6.15-16 shows the Net Present Value of a green roof installation in Washington DC and its determinant variables.

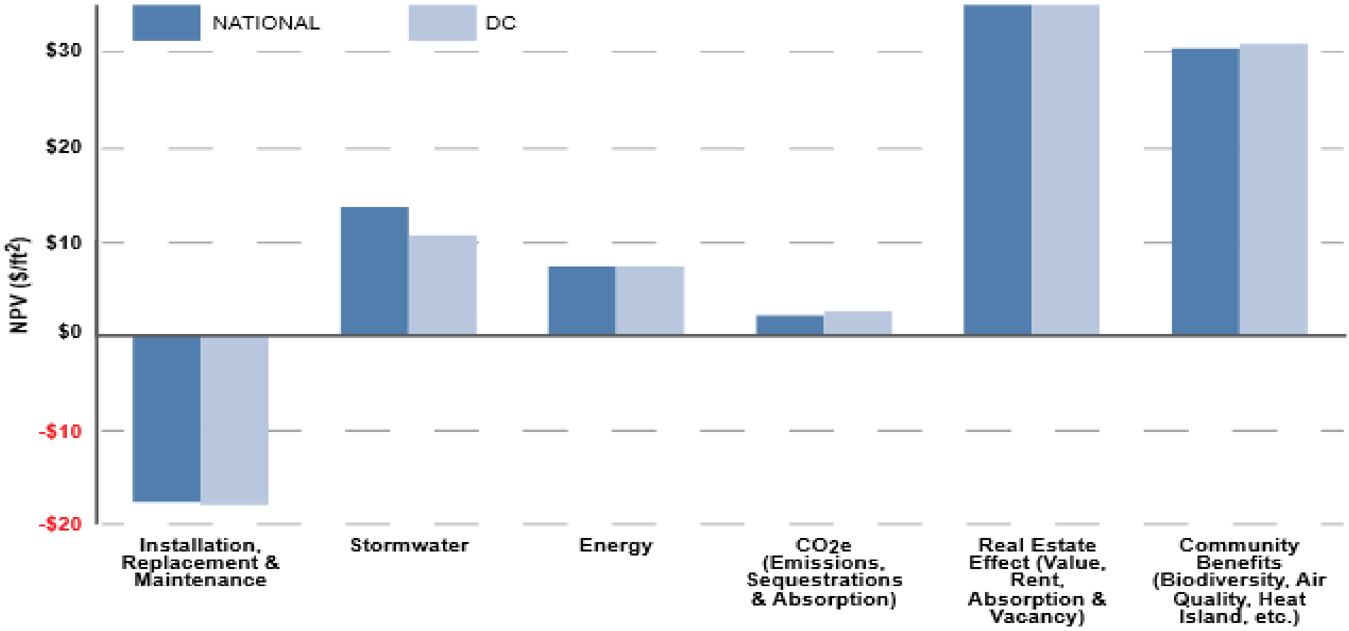



**Figure 6.15-16: NPV Cost-benefit analysis for green roofs versus black roofs (GSA Report, 2008)**

As we can see above for this case study Stormwater runoff reduction is not the most important benefit of a green roof neither could one economically justify such an investment solely based upon that specific benefit. Real estate valuation as well as community benefits – better air quality, lower heat island effect, higher biodiversity, etc. – are of higher importance. Nevertheless, the relative weight of each benefit is highly dependent on the socio-economic and meteorological context as well as in the climatic projections and respective vulnerabilities. For Cascais and as previously mentioned extreme precipitation events are one of the most crucial vulnerabilities projected meaning that water runoff is of extreme importance. At this level, the effectiveness of Green Roofs is well documented and dependent of the green roof type can go up to 90% for intensive green roofs.

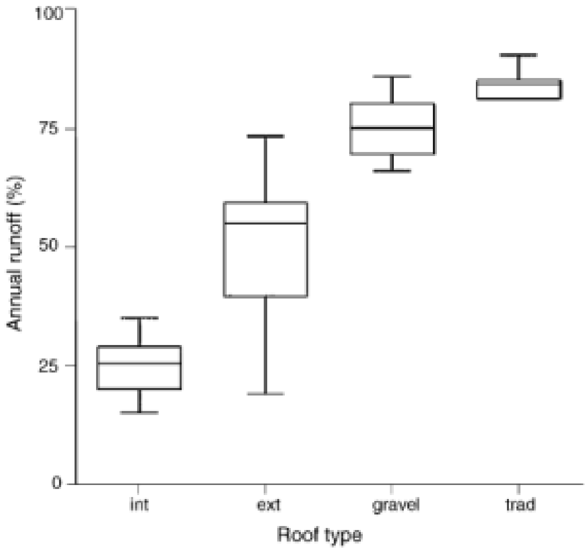



**Figure 6.15-17: Annual runoff for various roof types as a percentage of the total annual rainfall (Mentens et al 2006)**

The table below summarizes the main costs and benefits from the literature regarding green roofs installations:

**Table 6.15-14: Summary table of cost and benefits for green roofs**

| | Costs | Benefits |
|---|---|---|
| Construction | 40 – 180 EUR/m2 | Increased roof longevity (20 to 50 years) |
| Maintenance (40 years) | 100 EUR/m2 | Reduced roof maintenance (moderate uncertainty, depends on roof type) |
| Energy demand reduction | NA | 5 – 25 % |
| Stormwater runoff reduction | NA | 25% - 40% in winter<br>50% - 90% in summer |
| Carbon emissions | Data unavailable | Reduction in energy demand (overall carbon reduction depends on energy mix) |
| Improved Air quality | Data unavailable | Reduction of 0,2 kg/m2/year of air pollutants |
| Urban heat island effect | - | Reduction of summer temperature in neighbourhoods from 0.2ºC to 1ºC[79] |

**Rain gardens**

As mentioned before, in 2012 the municipality developed, together with FCT, a Protection Plan against floods in Ribeira das Vinhas. This study conceived three rainwater retention structures in different sections of the stream according to estimated peak flows and natural flow capacity. A summary table is presented below with overall cost and effectiveness of each of these green infrastructure measures:

[79] Blackhurst, Michael et all (2007), Cost-effectiveness of Green Roofs, *Journal of Architectural Engineering,* pp. 136-142

**Table 6.15-15: Water retention gardens in Ribeira das Vinhas**

| | Land Modelling and Landscape Design | Retention Structure | Total | Retention volume (Dam3) | Effectiveness[80] | EUR / M3 |
|---|---|---|---|---|---|---|
| Wrg 1 | 752.475 EUR | 174.400 EUR | 926.875 EUR | 328,5 | 0,711 | 2,82 |
| Wrg 2 | 1.337.640 EUR | 167.600 EUR | 1.505.024 EUR | 145,2 | 0,234 | 10,36 |
| Wrg 3 | 2.409.990 EUR | 215.600 EUR | 2.625.590 EUR | 426,4 | - | 6,15 |
| | | | **5.057.489 EUR** | | | |

From our perspective the Water retention garden 3 is highly strategic:

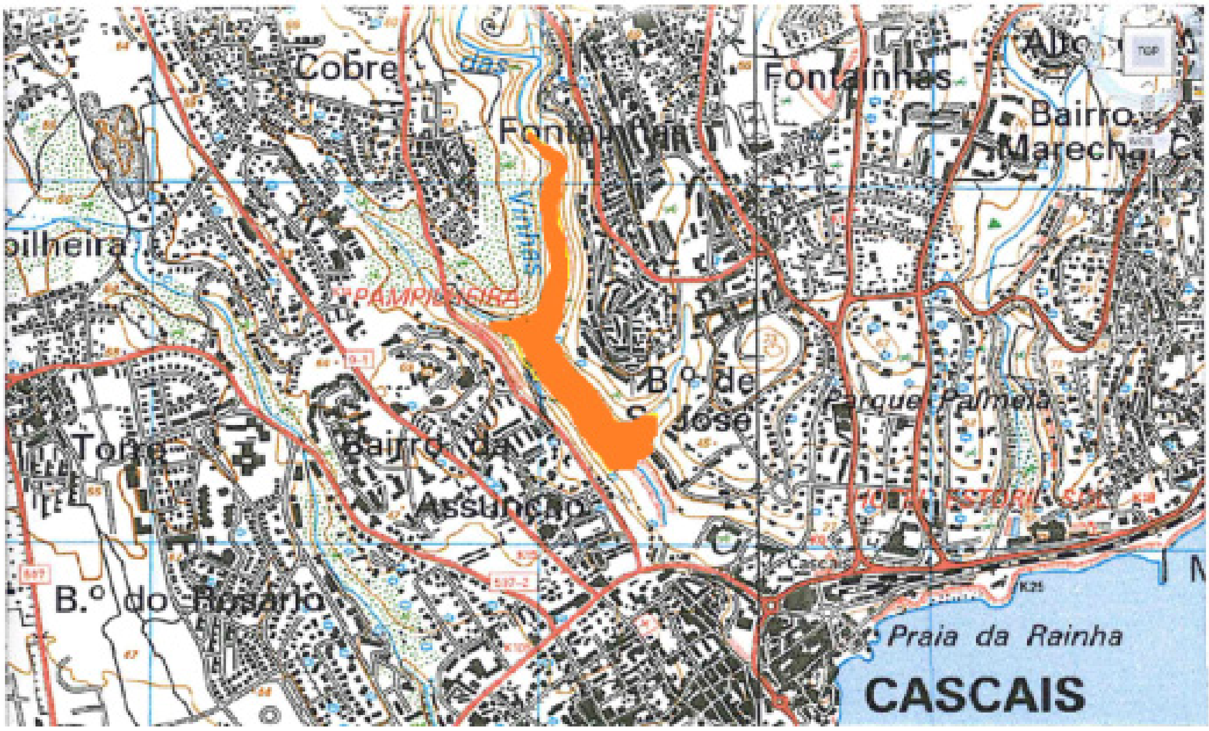



**Figure 6.15-18: Location of water retention garden 3**

[80] Retention capacity versus tributary volume for a T= 100 flood event

**Rainwater harvest**

As mentioned before rainwater harvesting presents itself mainly as a decentralized private solution which can be adopted by single or multi-family households as an adaptation measure to reduce flood risks but which also yields other benefits, namely economic benefits on water savings on such uses as toilet, laundry and garden. From a recent study done in Portugal – see table and figures below – the main insights are that the cost-benefit ratio highly depends on the price of water, its allocated uses and the size of the water tank. Also, due to the investment costs associated, a subsidy policy by the local municipality can be a fundamental role in promoting its proliferation.

A negative externality, which is, at this moment highly uncertain, is the effect it might have in the water course during summer periods where the rainwater harvest might contribute to the drying up of the stream with strong ecologic impacts.

Currently and for the Cascais Municipality the average houselhold costs for water supply (AA), waste management (SAN) and maintenance taxes (RSU) are around 254,69 EUR (120m3 of water consumption per year) meaning that a 1.000 EUR investment in such a system, without public subsidy, can have a payback period under 5 years. See Figure 6.15-20 for a Cost-benefit analysis in two Portuguese case studies (Lisboa and Guarda).

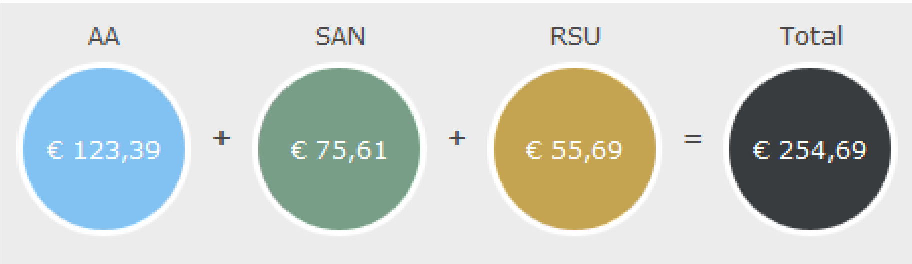



**Figure 6.15-19: Average annual household costs for water supply and water management in Cascais**

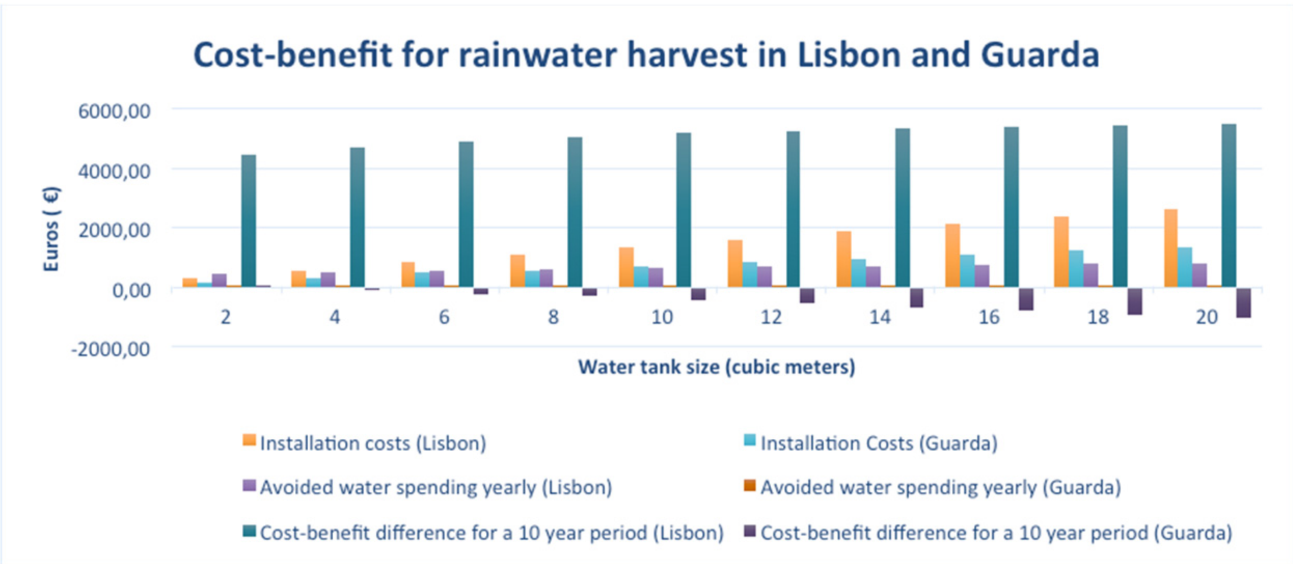



**Figure 6.15-20: Cost-benefit analysis for rainwater harvest in Lisboa and Guarda**

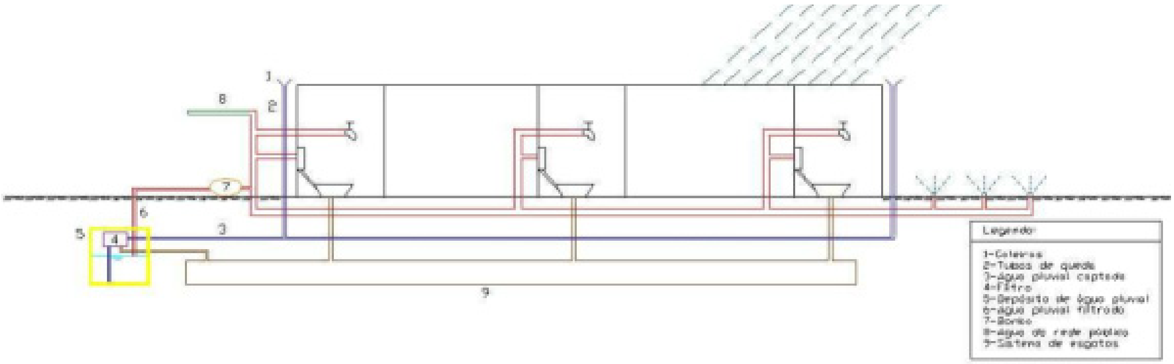


**Figure 6.15-21: Graphical representation of a rainwater harvest system and its uses (Lisbon)**

Rainwater harvesting can be a decentralized, economically sound solution with high effectiveness regarding Stormwater capture and retention. However, it is dependent on the number of uses that we allocate the rainwater collected as well as the lowering and simplification of licensing procedures.

**Green corridors and re-naturing/rehabilitation of streams**

According to the Municipality official budget the annual investment for tree planting, urban gardens expansion and the rehabilitation of Cascais streams - three major actions proposed and planned in the ecologic structure plan of Cascais – is of 50.000 EUR per year. However, its effectiveness in flood risk reduction is highly uncertain as the municipality does not have a detailed plan in which specific trees, locations, areas, etc. are mentioned. For that reason we can only take into consideration the investment costs.

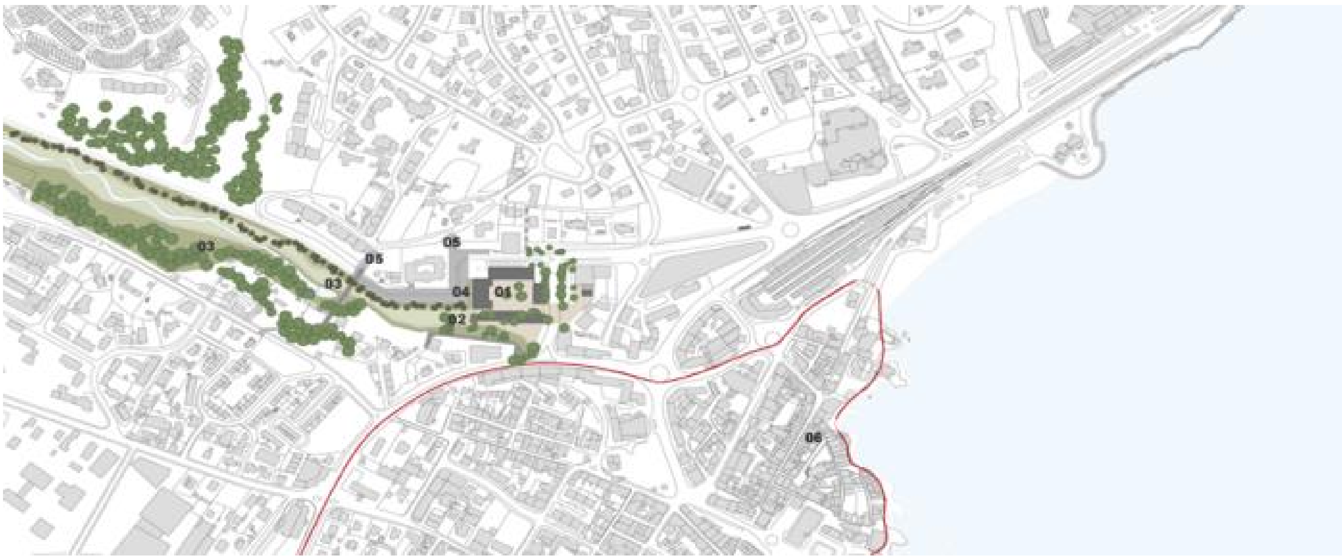


**Figure 6.15-22: Example of a green corridor project for the end section of Ribeira das Vinhas**

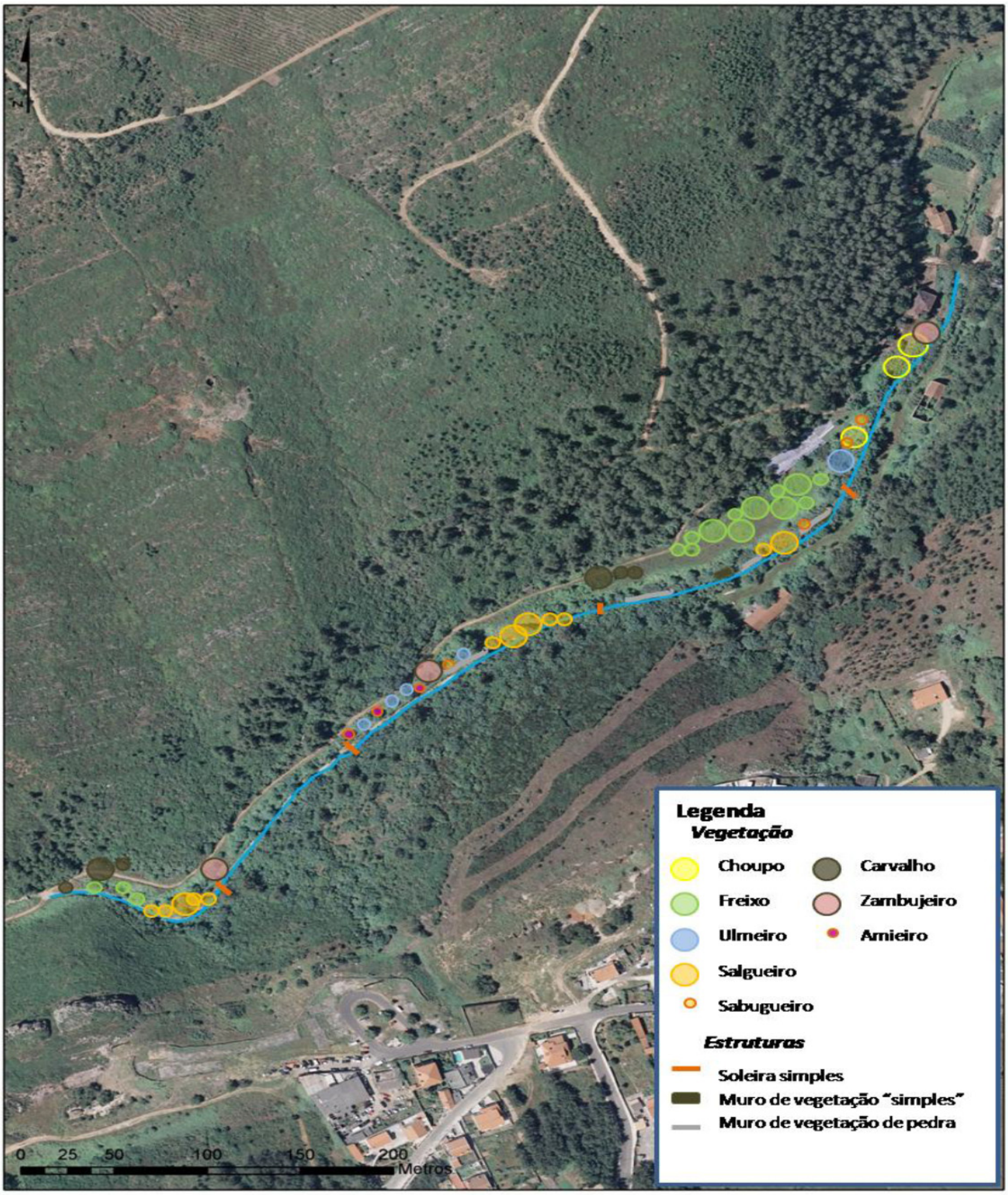



**Figure 6.15-23: Re-naturing of Ribeira das Vinhas, Quinta do Pisão 500 meters section**
Source: Gameiro (2010)

Example of a re-naturing project of Cascais Natura for a 500 meters section of Ribeira das Vinhas near Quinta do Pisão, with an overall budget of 8.500 EUR (Gameiro, 2010). This project has been considered to have a low environmental impact and high replicability in the Ribeira das Vinhas water course. Based on this information we found that the 50.000 EUR yearly budget for investment and maintenance costs for this stream from the

Municipality is appropriate and can yield important ecosystem services benefits which are not bounded to flood risk reduction.

**Step 5 – Evaluation and Prioritization**

Taking into consideration all of the data presented in sections 1 to 4 of this report we can only conclude that the stakeholders initial prioritization is consistent with the willingness to invest in such measures but not coherent with the experts MCA ranking, except for Green Roofs where both the initial stakeholders and the MCA invited experts did not prioritize or even considered for the Municipality. We believe that this has to do with both the uncertainty and lack of proper knowledge, as well as its high implementation costs.

Using a superficial cost-effectiveness analysis for a rainstorm extreme event (T = 100) for Ribeira da Vinhas we can make a strong argument towards rainwater catchment as it holds by far the best cubic meters of water to EUR ratio. This ratio might even increase dramatically from the stand point of the municipality if we consider that a great part of this investment can be made by the households themselves yielding private benefits. Subsidizing the adoption of such a measure might prove to be a cost-effective soft strategy for Cascais but demand elasticity and sensitivity curves have to be further researched.

Finally, and from a cost-benefit perspective, taking stock of the avoided damages reported for Cascais (1 MEUR for a 10 year period) and for Ribeira das Vinhas (approx. 100.000 EUR for the same period), only the Green corridors with the actual budget, and a subsidized option for private decentralized rainwater catchment would have a positive cost-benefit difference as the PBCA ratio points to regarding Green corridors.

**Table 6.15-16: Multi-criteria summary for prioritized flood adaptation measures in Cascais**

| Adaptation measure | Prioritization PECAC TOP 15 - 2010 | Prioritization (PECAC TOP 15 – 2013) | MCA Ranking[81] (PECAC 2.1 – Cluster experts) | PBCA Ratio | Investment costs to retain 1 Dam (T = 100 approx. for Ribeira das Vinhas basin) | Willingness to Invest within 3 years |
|---|---|---|---|---|---|---|
| Rainwater catchment | 13º | 5º | 14º | . | 130.000 EUR | 261.500,0 EUR |
| Green Corridors | 2º | 10º | 13º | 1,76 | - | 80.000,0 EUR |
| Green Roofs | NA | NA | 16º | - | 0,5 M EUR - 22 M EUR[82] | NA |
| Rainwater gardens | NA | NA | 11º | - | 10.360 EUR | 125.250,0 EUR |

Base proposal for an efficient and effective food adaptation strategy for Ribeira das Vinhas highlights the need for complementarity between actions as well as the need for better research and data regarding the use of Green Roofs where its externalities are also greater and rainwater harvest in the highly urbanized sections of the water stream. In the upstream sections we recommend the cleaning, enlargement and re-naturing of the stream, while in the downstream we recommend a combination between rainwater harvest and rain gardens. Finally, in downtown Cascais we propose an experimental Green Roof installation in order to assess the storm water runoffs, the cooling effect for urban heat waves and the energy reduction in buildings.

[81] Out of 16 adaptation measures clustered into the Water (8) and Biodiversity (8) sectors of analysis

[82] Based on empirical results for water retention in Green roofs which varies from 20 liters to 250 liters per square meter.

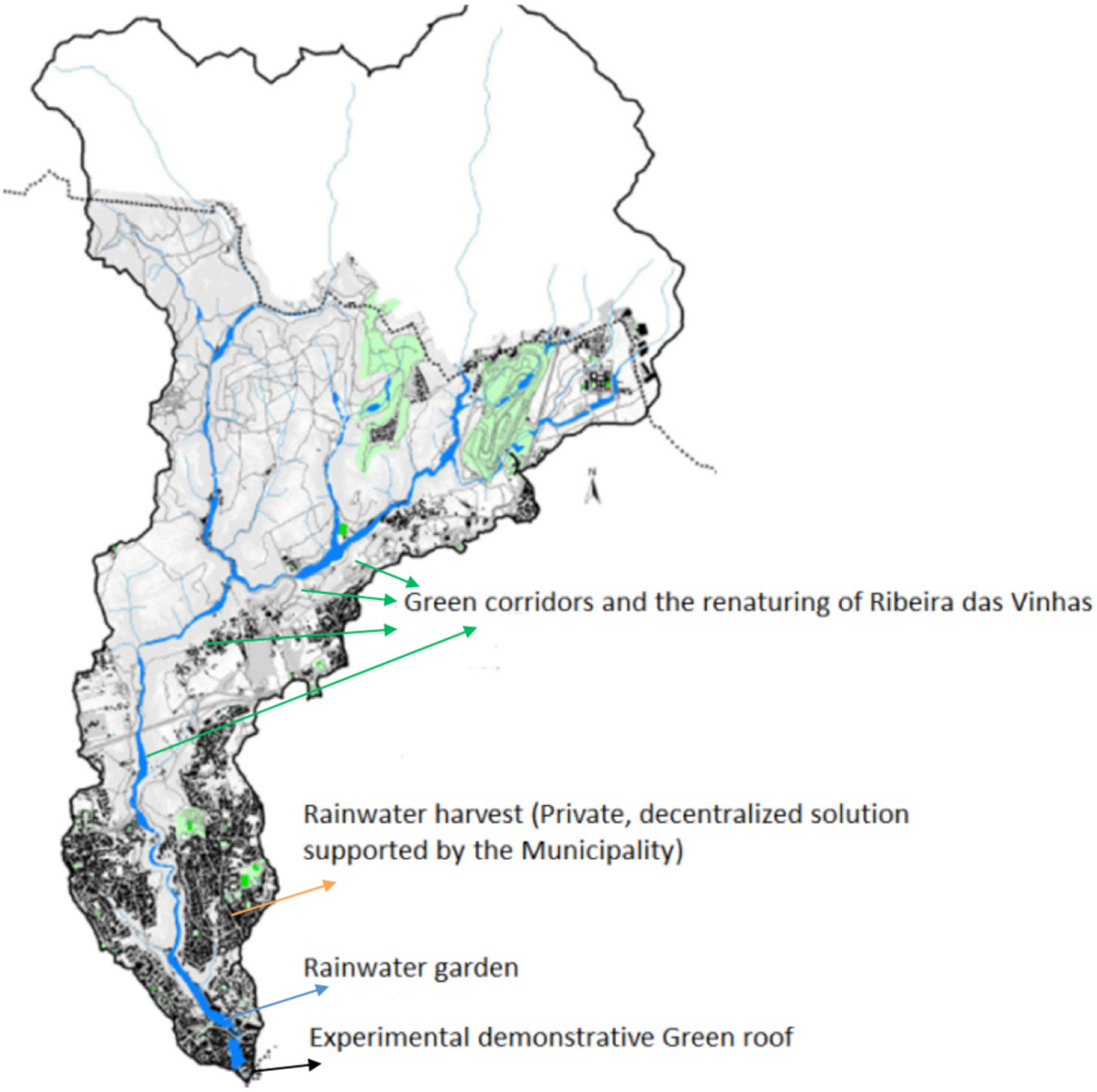



**Figure 6.15-24: BASE recommended action-pan for flood adaptation in Ribeira das Vinhas**

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## 6.16 Tagus Water District (Madrid)

Ana Iglesias, Pedro Iglesias, Luis Garrote, Alvaro Sordo, Luis Mediero, Berta Sanchez, UPM

Aline Chiabai, Sebastien Foudi, Marc Neumann, Marta Olazabal, Joseph Spadaro, BC3

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

**What is the climate change related problem/risk you would like to reduce by adaptation?**

*Extreme temperatures and water scarcity*

Climate in the Madrid region is characterized by having hot and dry summers and cool winters. Temperatures show a very sharp gradient following a similar pattern of rainfall. The hottest month is August and January the coldest. Summer becomes hot, so are long and cold winters, warm summers and spring and autumn are short seasons and irregular but very marked. Typically temperatures are higher in cities than on the outskirts and this difference increases on stable periods for the presence of the anticyclone, giving rise to the phenomenon called urban heat island, an atmospheric situation that occurs in big cities and involves rapid increase in temperature form the outskirts to the city centre, where buildings and asphalt off the heat accumulated during the day. One of the most outstanding characteristics of the Madrid climate is the irregularity of the inter-annual rainfall.

**Which assets and sectors are at risk under current climate variability?**

- Health and Social Policies, Biodiversity & Ecosystems, Disaster management among others.

**Which adaptation or protection measures are already in place?**

- Non-structural: Awareness raising, Disaster response management, Risk transfer tools.
- Structural: Water conservation, Water saving measures, Ground water management, Water technology, Measures to minimise exposure to diseases

**How do these risks presumably change due to climate and socio-economic change?**

- All of the above mentioned risks are taking place. Climate Change will increase their effects.

**What are the main drivers, impacts and affected sectors?**

- Water Management, Human health, Agriculture, Human settlements and infrastructure, Biodiversity and ecosystems.

**Which climate and socio-economic scenarios are used?**

Two choices:

1. Representative Concentration Pathway RCP 8.5 combined with Shared Socioeconomic Pathway SSP 5, which represent a conventional high development, and
2. RCP 4.5 combined with SSP2, which giving the image of a world more concerned with the environmental problems.

**Which adaptation tipping points can be identified?**

The adaptation pathway approach is not applied for the Tagus case study.

**Can adaptation tipping points, critical levels for adaptation, be defined for this current strategy?**

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

**What are the alternative adaptation measures?**

*What are the primary and secondary objectives of adaptation?*

The main objective of adaptation is to reduce the vulnerability of society to the effect of water scarcity and high temperatures, with special attention to the most disadvantaged.

Water is a limited resource that supports human activities. Climate change is only one of many pressures faced by water management today and in the future. However climate change is a very significant pressure since it has a direct impact on all aspects of water for people. A range of adverse impacts include reduced water availability and more frequent extreme events, such as droughts. These negative impacts may put water resources management, certainly at the level of individual land managers and regions, at significant risk under uncertain conditions. This uncertainty is especially relevant for the water sector because it links to health, agriculture and food security, industry and energy, ecosystems, cities, and culture. Climate change comes in conjunction with high development pressure and increasing populations, which poses a major challenge on water management.

*What are potential measures to meet these objectives?*

- Reuse of urban water
- Water rights exchange programmes
- Greening the city: green roofs
- Well defined Heat Health Warning System

*What is your baseline option (the “business-as-usual”-option)?*

Climate change is only one of many pressures faced by water and health management today and in the future. Some of the measures used to cope with current hazards have yet an exceptional character and may not be enough for future scenarios.

*What is the ambition level of this baseline strategy?*

Most of the stakeholders try to maintain current protection levels seen from a single sector point of view. The case study analyses trade-offs and synergies between sectors to ensure a more resilient society under future climate conditions.

*Is current backlog of investments for adaptation measures included or excluded?*

All investment options are included.

*Does it include only planned adaptation or also autonomous, non-planned adaptation?*

It includes planned adaptation and changes on behaviour of the population.

*Are there complementary measures? Is it appropriate to bundle these measures?*

All measurements are complementary and studied only considered individually to apply the appropriated methods of analysis.

**What are alternative adaptation pathways?**

The adaptation pathway approach is not applied for the Tagus case study.

**Step 3 - Evaluation Criteria and Method**

**Step 3a Selection of evaluation criteria**

**Which evaluation criteria should be used?**

*What are the relevant positive and negative properties of the measures (costs and benefits) to be considered in the evaluation process (economic, ecological and social effects)?*

Water is needed for most of the adaptation measures to cope with climate change in the health sector. Options analysed are the reuse of wastewater and the right exchange. The drawbacks of these measures are (1) implementation and maintenance costs and (2) impacts on the ecosystems.

*What is the appropriate unit to measure each of these criteria?*

Several units are used to measure different criteria. Public health has usually used cost-effectiveness analysis (CEA), which estimates the cost of achieving a certain health impact, measured as number of deaths, cases or DALY avoided. The method is used to identify the measure with the highest cost-effectiveness. Cost-benefit analysis (CBA), on the other hand, estimates and compares costs and benefits in monetary terms, in order to identify the measure with the highest net benefit. Both methods focus on the social costs of implementation, defined as the aggregated opportunity costs incurred by the society if the measure is put in place. The costs of a measure are those associated to the direct implementation of the measure, to the effort needed to improve adaptive capacity (institutional costs such as those related to infrastructures, training, information) and to the resource reallocation, these latter being usually not included as difficult to estimate.

*Is the performance of the adaptation options measured in qualitative, monetary or other quantitative terms?*

The general performance of the adaptation measures is evaluated using qualitative methods. Specific measures are evaluated both in quantitative and semi-quantitative terms using cost benefit analysis and Fuzzy Cognitive Mapping method.

**Step 3b Selection of evaluation method(s)**

**What is the appropriate evaluation method?**

*Is it possible to express all relevant cost and benefit criteria in monetary terms?*
*(→ cost-benefit analysis)*

There are generally approved in literature methods to correlate the HIA to monetary figures, thus a Cost-Benefit analysis is used for the health sector.

**Step 4 - Data collection**

**What are the costs and what are the benefits of the alternative adaptation options?**

*What potential data sources are available, including damage & impact assessment methods or existing CBA studies on adaptation measures?*

- Water: Ministry of Health, Water Quality Department, River Basin Authority, CEDEX (Centre for Hydrographical Studies).
- Health: The main data source is the Health Ministry through the Health and Climate Change Observatory. Additional data sources are the Regional Government of Madrid and the Carlos III Health Institute.

In the case of health, the benefits of a heat-health warning system (HHWS) are estimated based on an epidemiologic relationship relating climate factors and confounders (pollution, noise, etc.) to mortality. Measuring benefits of

HHWS in terms of avoided death means to firstly estimate the effectiveness of a HHWS. The task is a very challenging one; Toolo et al. 2013 indicates that only 7 papers performed a measure of effectiveness but none of them define a causal relationship and only 1 paper presents a CBA. Indeed isolating the HHWS is a very complicated and controversial issue due to comparability of heat waves, social changes, learning effects, etc. We will estimate the impacts of having an efficient HHWS with a statistical epidemiologic method, based on data specific to Madrid. This method will give us the avoided death thanks to an efficient HHWS. The analysis will be conducted under climate change scenarios. The estimation of the benefits of green infrastructure is challenging in determining the cooling effect of the measures and their capacity to reduce the urban heat island effect.

Alongside with the modelling of the future climate data of the estimations of the effectiveness of adaptation measures are obtained from literature. See the references chapter.

*How do the adaptation options perform with regard to each of the cost and benefit criteria selected in step 3a?*

There are no CBA analysis for green roof that would correspond to a Mediterranean climate with continental influence like Madrid (classification of Köppen). We therefore estimated the CBA, the potential benefits of green roof is linked to the climate change.

Green roofs generated an exhaustive list of services and disservices (Table 6.16-1). We adapted this list form Berndtsson, 2010; Oberndorfer et al., 2007; Wang et al., 2014). For the CBA on green roof, we modelled the benefits of **energy saving** due to a reduced necessity of indoor cooling and reduced number of days where air conditioning is used thanks to urban heat island (UHI) reduction scenarios, **carbon footprint** reduction, **avoided mortality** due to outdoor UHI reduction, **water retention services and avoided maintenance costs**. We can distinguish the private and public services. A public services is a services that follows the definition of a public good (non-rivalry and non-excludability in its use). By intangible services, we refer to services which valuation cannot be done through a market value. Tangible means that the valuation units is derived from a market value.

**Table 6.16-1: List of costs and benefits of adaptation measures**

| Adaptation measures | Cost | Benefits | Modelled | Private / Public | Physical units of the services | Tangible/Intangible |
|---|---|---|---|---|---|---|
| Heat-Health Warning System | Implementation , personal cost. The variable cost is a function of the number of days of alert | Avoided mortality attributable to heat wave | Yes | Public | Avoided mortality | Tangible |
| Green roofs | Implementation + maintenance | Energy Saving | Yes | Private | Kilowatt hour | Tangible |
| | | Water retention | Yes | Private/ Public | Cubic meter | Tangible |
| | | Carbon footprint reduction | Yes | Public | CO2 | Tangible |
| | | Health | Yes | Public | Avoided mortality | Tangible |
| | | Urban Heat Island reduction | Yes | Public | Temperat ure | Intangible |
| | | Habitat for biodiversity | No | Public | - | Intangible |
| | | Air quality (positive and negative services) | No | Public | - | Intangible |
| | | Sonic services: noise reduction, pleasant noise | No | Public | - | Intangible |
| | | Aesthetic | No | Public | - | Intangible |

Below we present in section A, the green roof CBA with subsections for the costs and selected benefits and in a section B the CBA for the Heat Health Warning system of Madrid.

**A – Green roofs costs and benefits**

1. *Potential of green roof in Madrid and its costs:*

We consider that green roofs can be built over the residential and commercial area of Madrid. We use the land uses of 2009. The total area covered by urban buildings is 9527.70 Ha in 2009 (Statistical Institute of Madrid Community), about 43% of the city. We do not use the industrial area since we were not able to collect data to estimate the benefits of energy savings in industrial areas but these areas are eligible areas for green roofs.

Sproul et al. (2014) give cost estimates for 22 case studies in the US. The maintenance cost is 2.29EUR/m2/year. The lowest cost of the first installation is 85EUR/m2, the median is 135EUR/m2 and the maximum 178EUR/m2. Oberndorfer et al. (2007) gives range of 80/240 EUR/m2 for extensive roofs.

As noted in Oberndorfer et al. (2007) water needs for green roof are negligible as much as plant species are adapted to the local climate. We do not consider irrigation in the maintenance cost. We consider a 30 years lifespan for the green roof and a renovation of the roof after the age. For traditional roofs we use a 20 years lifespan. We use data collected from CYPE Ingenieros, the Catalonia Institute of Construction Technology – Itec and two manufacturer of building products DANASO and TEXSA for green and traditional roofs. We compute the additional cost of green roofs (Table 6.16-2).

**Table 6.16-2: Unit additional cost of green roof installation**

| EUR/m2 | Low | Average | High |
|---|---|---|---|
| New green roof | 26 | 36.5 | 47 |
| Existing green roof | 51 | 164 | 277 |
| Maintenance/year | 1.3 | 2.6 | 4 |

We consider that green roof would replace already the installed conventional roofs and simulate **4 scenarios of green roofs coverage** over the buildings area of Madrid: **5%, 20%, 50% and 100%.**

Five different discount rates are considered for the period 2020-2100. We obtain the following discounted costs of transformation of existing roofs, for the average unit cost and under the socio-economic scenarios SSP2 and SSP5.

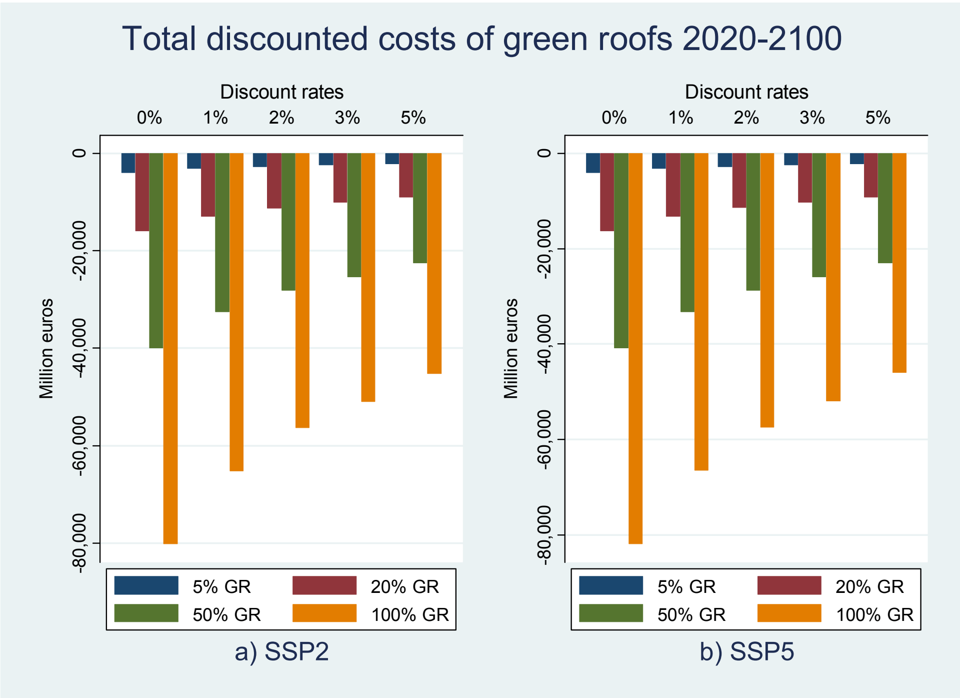



**Figure 6.16-1: Discounted additional total costs of green roofs in Madrid**

The following graph illustrates the difference between the 2 socio-economic scenarios, SSP2 and SSP5 in the range of costs. Given that the different green roof coverage scenarios are linear, we represent only the 5% coverage scenario and give the range of estimated costs (low, average and high).

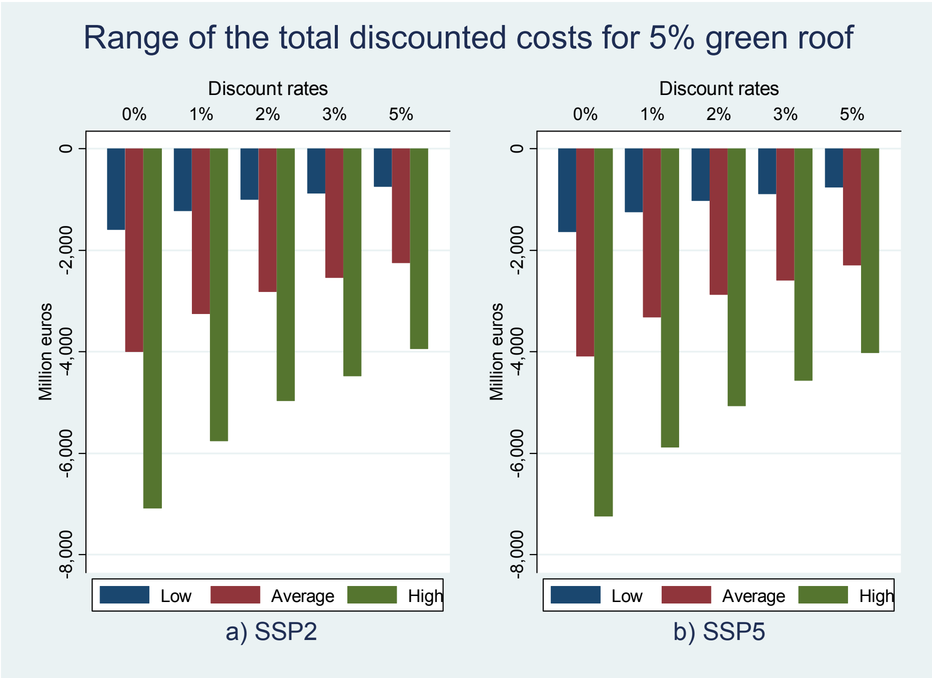



**Figure 6.16-2: Range of estimates of discounted additional costs of green roofs for a 5% coverage**

The investment consists in a fixed initial cost and a flow of discounted maintenance costs. Table 6.16-3 gives this repartition for the 5% roof coverage scenario, the other scenarios of green roof coverage (20%, 50% and 100%) are proportional to the 5% coverage scenario. We see that over 2020-2100, the maintenance cost is higher than the initial costs until the 3% discount rate for average values.

**Table 6.16-3: Discounted initial and maintenance costs for 5% green roof coverage**

| | Total Initial cost, m EUR | | | Discounted total maintenance cost over 2020-2100*, m EUR | | |
|---|---|---|---|---|---|---|
| **Discount rate** | **Low** | **Medium** | **High** | **Low** | **Medium** | **High** |
| 0% | 279 | 898 | 1518 | 524 | 1107 | 2029 |
| 1% | 279 | 898 | 1518 | 338 | 734 | 1366 |
| 2% | 279 | 898 | 1518 | 230 | 514 | 971 |
| 3% | 279 | 898 | 1518 | 164 | 378 | 725 |
| 5% | 279 | 898 | 1518 | 98 | 234 | 458 |

Note: Includes the renewing of the roof every 30 years. Under scenario SSP2.

These estimates assume that there are no economies of scales. With economies of scales we could expect that the costs of construction would decrease as adoption of green roofs becomes larger.

**Contribution of green roof to the reduction of urban heat island effect**

The phenomenon of urban heat island reflects the fact that urban areas are warmer than the surrounding rural areas. In the absence of sufficient stored moisture, solar energy is to heat artificial impervious surfaces instead of being naturally used to evaporate water as it occurs in rural and open areas. This evaporation creates a cooling effect and thereby reduces the temperature of the surroundings. In cities, others source of warming originates from anthropogenic activities like among others the use of energy for transportation, cooling buildings, lighting, which exacerbates the urban heat island effect. The use air conditioning use in a city would contribute up to 2ºC in urban heat island (Salamanca et al., 2012; Tremeac et al., 2012; Wen and Lian, 2009). In Madrid, the urban heat island effect reaches the 5-6ºC (Yagüe and Zurita, 1991) and is not spatially uniform over the city (Fabrizi et al., 2011). Cooling cities with albedo changes or vegetation is an adaptation measures whose cooling potential depends upon factors like the local climate, the extension and the characteristics of cool/green roofs (Santamouris, 2014)

The effectiveness of green infrastructure solutions in reducing urban heat island, i.e. changes in albedo, planting curb side with trees, installing green roofs and green walls are studied at experimental micro scales (Alexandri and Jones, 2008, 2007; Kumar and Kaushik, 2005) and at simulated meso scales (Bass et al., 2002; Georgescu et al., 2014; Rosenzweig et al., 2006; Salamanca et al., 2012; Susca et al., 2011; Taha, 1999). At meso scale, the urban heat island mitigation depends on the scenario of adaptation: only single green infrastructure measures[83] and others a bundle of measures (Table 6.16-4). The higher mitigation effect is obtained with the mixed of adaptation measures (Rosenzweig et al., 2006; Salamanca et al., 2012; Taha, 1999) and when the soil moisture is artificial increased (Bass et al., 2002).

In a climate change context, Georgescu et al. (2014) simulate the UHI reduction for six US states and found an UHI reduction between 0.2 and 1.2ºC from green roofs.

[83] Although changes in albedo is a green infrastructure measures we included it in this category as it also represents the simulated effect of green roof installation.

**Table 6.16-4: Urban heat island mitigation from adaptation measures**

| | | | | | UNIT: Degree Celsius | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Single adaptation mesaures | | | | | Mixed Adaptation Measures | | |
| **Authors** | **year** | **Country** | **City** | **Coverage** | **Green Roof** | **Irrigated green roof** | **Albedo change (Light roof)** | **Planting curbside with trees** | **Open space planting** | **Ecological infrastructures: green roof, trees, grass** | **Air Cond. off,Insulation, Albedo** | **Plant, Albedo** |
| Bass et al. | 2003 | Canada | Toronto | 5% total land area of the city | 0.5 | 1 to 2 | NC | NC | NC | NC | NC | NC |
| Rosenzweig et al. | 2006 | US | New York city | 100% of available areas | 0.33 | NC | 0.275 | 0.22 | 0.11 | 0.66 | NC | NC |
| | | | | 50% of available areas | 0.154 | NC | 0.16 | 0.12 | 0.06 | 0.70 | NC | NC |
| Salamanca et al. | 2012 | Spain | Madrid | 100% | NC | NC | NC | NC | NC | NC | 1 to 2 | 1 to 2 |
| Taha et al. | 1999 | US | Los Angeles | 100% | NC | NC | NC | NC | NC | NC | NC | 1.5 |
| | | | Chicago | | NC | NC | NC | NC | NC | NC | NC | 1 |
| | | | Atlanta | | NC | NC | NC | NC | NC | NC | NC | 1 |
| | | | Washington | | NC | NC | NC | NC | NC | NC | NC | 0.5 |
| | | | Philadelphia | | NC | NC | NC | NC | NC | NC | NC | 1 |
| | | | New York | | NC | NC | NC | NC | NC | NC | NC | 1 |
| | | | Houston | | NC | NC | NC | NC | NC | NC | NC | 1 |
| | | | Dallas | | NC | NC | NC | NC | NC | NC | NC | 1 |
| | | | Phoenix | | NC | NC | NC | NC | NC | NC | NC | 1 |
| | | | Miami | | NC | NC | NC | NC | NC | NC | NC | 0.5 |
| Georgescu et al | 2014 | US | California | 100% | 0.24 | NC | 1.45 | NC | NC | NC | NC | NC |
| | | | Arizona | | 0.15 | NC | 0.47 | NC | NC | NC | NC | NC |
| | | | Texas | | 0.46 | NC | 1.24 | NC | NC | NC | NC | NC |
| | | | Florida | | 0.21 | NC | 0.41 | NC | NC | NC | NC | NC |
| | | | Mid Atlantic | | 1.19 | NC | 1.8 | NC | NC | NC | NC | NC |
| | | | Chicago/Detroit | | 0.85 | NC | 1.37 | NC | NC | NC | NC | NC |

Based on (Table 6.16-4) and expert consultation, we extrapolate for the city of Madrid the UHI reduction for different coverage of green roofs. We assume arbitrarily a proportional relation between green roof coverage and UHI mitigation. A critical area of green roof is required to observe a cooling effect at the city scale, we observe that below 50% the temperature reduction is negligible Table 6.16-5).

**Table 6.16-5: UHI mitigation potential in Madrid**

| | Green roof coverage | | | |
|---|---|---|---|---|
| | **100%** | **50%** | **20%** | **5%** |
| Average, ºC | 0.30 | 0.15 | 0.06 | 0.015 |
| min, ºC | 0.10 | 0.05 | 0.02 | 0.005 |
| max, ºC | 0.5 | 0.25 | 0.1 | 0.025 |

Source: Adapted from Table 6.16-4 and expert consultation

Urban heat island makes people in urban areas more exposed to heat waves which would increase heat related mortality (Rey et al., 2009) and also increase the demand of energy for cooling with air conditioning which in turns increase the outdoor temperature. We therefore consider in this analysis that the urban heat island reduction from green roof impacts urban health and the demand of energy for cooling.

**Benefits of green roofs: energy consumption reduction**

Energy consumption reduction obtained from green roof originates from better insulation of the building, which results in lower electricity demand for cooling and from a reduction of the number of days where air conditioning is used due to UHI reduction obtained from green roofs.

Green roofs by providing a better insulation of building generate energy savings for the building (Castleton et al., 2010). Although the savings are decreasing with the distance to the roof (Saiz et al., 2006), an average rate energy saving can be calculated. In Madrid, Saiz et al. (2006) shows that green roof reduced by 6% the cooling load in summer on an 8-story residential building. Salamanca et al. (2012) find a 4.82% and a 3.59% energy consumption reduction for albedo modification and insulation of the roof in Madrid and with an indoor temperature of 25ºC maintained by air conditioning.

A reduction of outdoor temperature due to green roof's cooling effect would reduce the number of days where air conditioning is used. The Spanish regulation on thermal facilities in buildings recommend a threshold of 28ºC for outdoor temperature and a target indoor temperature of 25ºC. With these thresholds, Izquierdo et al. (2011) derived the energy load for air conditioning for residential uses in Madrid Community. For the 38% of residential buildings equipped with air conditioning in Madrid and adjusting for migration during summer holidays they found that the electricity consumed by air conditioning units accounted for about 6.7% of the total consumption of electricity, or 920 KWh per home equipped with air conditioning. We use the average of energy consumption and price over 2009-2013 for residential units in Madrid and (Madrid Municipality, 2015; Red Eléctrica de España, 2014) to estimate and value these two sources of energy. We use the outdoor temperature of 28ºC as a threshold to compute the number of days where air conditioning is used and the number is days where the urban heat island reduction contribute in not using air conditioning.

**Table 6.16-6: Total discounted benefits of energy savings services from green roofs for 2020-2100**

| | | | Discount rates | | | | |
|---|---|---|---|---|---|---|---|
| | | **Green roof coverage** | **0%** | **1%** | **2%** | **3%** | **5%** |
| **Climate change scenarios** | **SSP2 and Rcp45** | **5%** | 12.3 (9.2-15.7) | 8.8 (6.4-11.1) | 6.6 (4.7-8.3) | 5.1 (3.6-6.5) | 3.4 (2.3-4.4) |
| | | **20%** | 43.6 (28.4-65.8) | 30.6 (19.8-46.4) | 22.7 (14.6-34.4) | 17.6 (11.2-26.7) | 11.8 (7.3-17.9) |
| | | **50%** | 114.2 (71.5-150.5) | 79.6 (49.8-105.3) | 58.5 (36.6-77.5) | 45 (28.2-59.7) | 29.8 (18.7-39.5) |
| | | **100%** | 218.5 (145.1-289.2) | 152.3 (100.8-201.6) | 111.8 (73.8-148.1) | 86 (56.6-113.9) | 56.8 (37.4-75.4) |
| | **SSP5 and Rcp85** | **5%** | 13 (8.5-16.9) | 8.8 (5.6-11.5) | 6.3 (3.9-8.3) | 4.8 (2.9-6.3) | 3.1 (1.8-4.2) |
| | | **20%** | 48.1 (31.4-66..8) | 32.5 (21.2-45.5) | 23.2 (15.1-32.8) | 17.5 (11.4-24.8) | 11.2 (7.4-16.2) |
| | | **50%** | 119 (80-156.4) | 81 (54.106.8) | 58.3 (38.6-77.2) | 44.2 (29-58.7) | 28.8 (18.6-38.4) |
| | | **100%** | 232.5 (157.8-310.5) | 157.9 (106.8-211.5) | 113.6 (76.4-152.5) | 86 (57.6-115.6) | 55.9 (37.2-75.4) |

Notes: Low and high values in parentheses; Unit: m EUR.

The discounted benefits from energy savings services delivered by green roofs are increasing with the coverage of green roof. For a discount rate of 2%, it varies from 6.6 m EUR for a 5% of green roof coverage under SSP2 and Rcp4.5 to 113.6 m EUR for a full coverage in Rcp8.5 and SSP5.

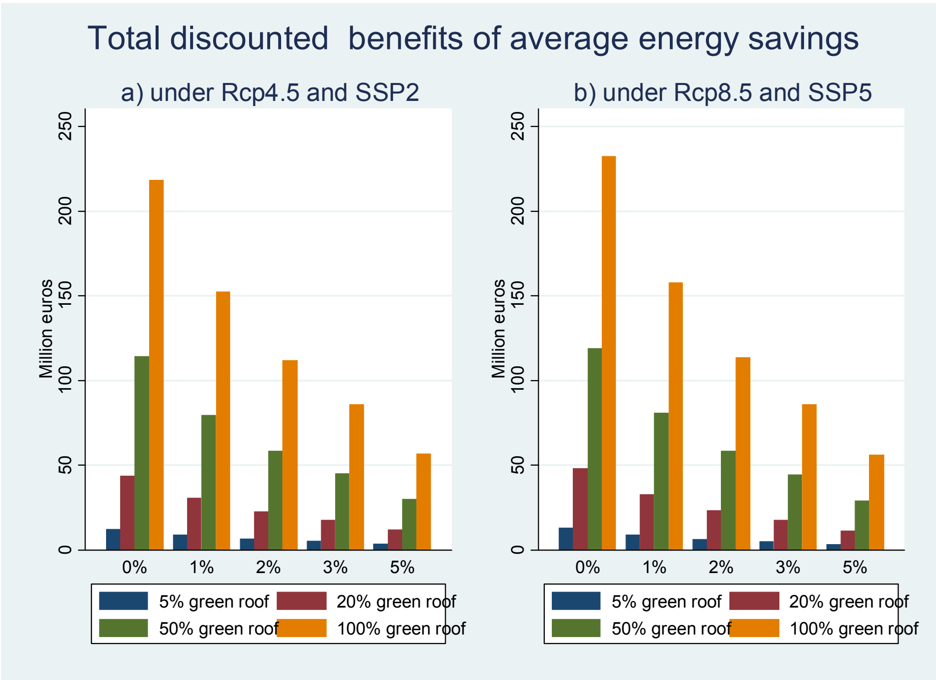



**Figure 6.16-3: Total discounted benefits of average energy consumption reduction, 2020-2100**

The difference of energy saving between the two RCPs depends on the number of days where the AC is on, i.e. whenever the maximum of the monthly average temperature exceeds 28ºC. Then, we can see that the difference in total energy savings between the socio-climatic scenarios is not very high (Figure 6.16-3).

**Benefits of green roofs: Carbon footprint reduction**

The carbon footprint is reduced with green roof by the sequestration of $CO_2$ by the plants and by the reduction of the consumption of electricity used for air conditioning.

Green roofs sequester carbon in plants and soils. During photosynthesis carbon is removed from the atmosphere and is stored into the plants. Part of the carbon is also transferred to the soil as a natural process to increase soil organic matter necessary to the plant growth. Getter et al. (2009) and Whittinghill et al. (2014) decomposed carbon sequestration of a green roof as carbon sequestrated in the aboveground biomass, in the root biomass and in the substrate organic matter. In the urban landscape, carbon sequestration capacity of green has received less attention than other natural support like street trees. Wang et al (2014) reviewed the literature for trees. Getter et al. (2009) study with a 6 years experiments the carbon sequestration potential of extensive green roofs in Michigan and Maryland. They found an average carbon sequestration capacity of 162 g C/m$^2$ with a large variability: The site with the minimum carbon sequestration registered 73/m$^2$ and the maximum observed carbon sequestration is 276/m$^2$.

Avoided emissions uses of electricity for air conditioning reduces $CO_2$ emissions. The $CO_2$ footprint of electricity production depends on the resources used to produce electricity. In Spain or the period 2009-2013, the carbon footprint is estimated on average at 0.250 kg $CO_2$/Kwh, with low value of 0.21 kg $CO_2$/Kwh observed in 2010 and a high value of 0.30 kg $CO_2$/Kwh in 2012 (Red Eléctrica de España, 2013).

**Table 6.16-7: Total discounted benefits of $CO_2$ emission reduction services from green roofs for 2020-2100**

| | | | Discount rates | | | | |
|---|---|---|---|---|---|---|---|
| | | **Green roof coverage** | **0%** | **1%** | **2%** | **3%** | **5%** |
| **Climate change scenarios** | **SSP2 and Rcp45** | **5%** | 5.9 (1.8-28.4) | 3.8 (1.1-18.1) | 2.5 (0.8-12.2) | 1.8 (0.5-8.6) | 1.1 (0.3-5) |
| | | **20%** | 23.1 (6.8-114.9) | 14.8 (4.3-73.2) | 10 (2.9-49.2) | 7.1 (2.1-34.8) | 4.1 (1.2-20.1) |
| | | **50%** | 58.5 (16.9-283.5) | 37.3 (11.1-181.3) | 25.2 (7.4-121.1) | 17.8 (5.2-85.4) | 10.4 (3-49.4) |
| | | **100%** | 116 (31-563.7) | 74 (21.7-358.4) | 49.8 (14.6-240.4) | 35.4 (10.4-170) | 20.6 (6.1-98) |
| | **SSP5 and Rcp85** | **5%** | 6.2 (1.8-29.8) | 3.9 (1.2-18.6) | 2.6 (0.8-12.6) | 1.9 (0.5-8.9) | 1.1 (0.3-5.1) |
| | | **20%** | 24.3 (7.1-118.9) | 15.4 (4.5-75.2) | 10.3 (3-50.3) | 7.3 (2.1-35.4) | 4.2 (1.2-20.3) |
| | | **50%** | 60.6 (17.9-293.6) | 38.5 (11.4-185.8) | 25.8 (7.6-124.2) | 18.2 (5.4-87.5) | 10.6 (3.1-50.2) |
| | | **100%** | 120.7 (35.7-586.7) | 76.6 (22.6-371.6) | 51.3 (15.2-248.1) | 36.3 (10.7-174.8) | 21 (6.2-100.2) |

Notes: Low and high values in parentheses; Unit: m EUR.

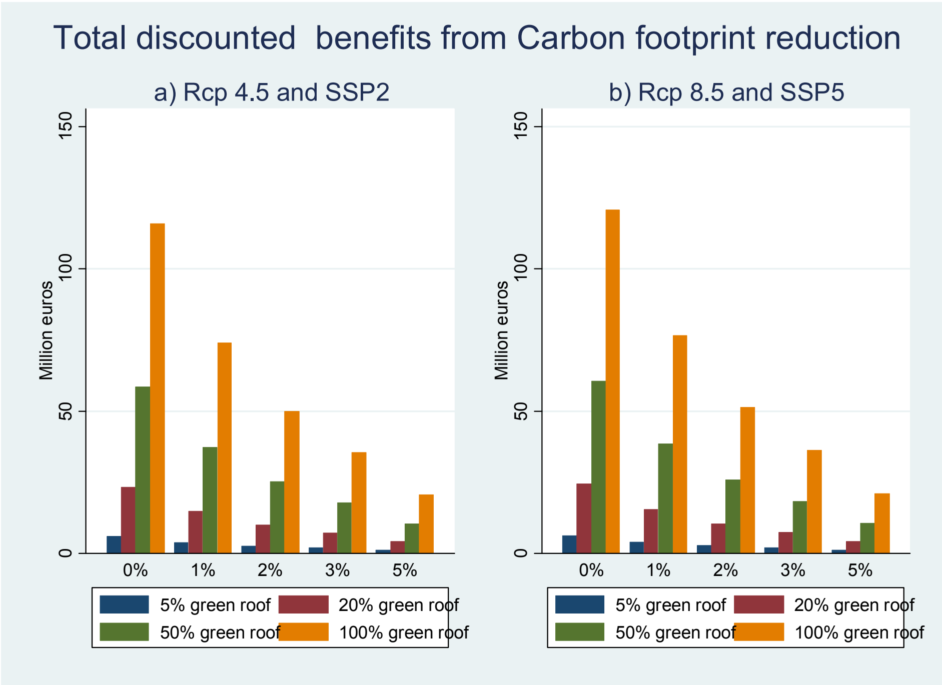



**Figure 6.16-4: Total discounted benefits of carbon footprint reduction**

**Benefits of green roof: Health**

High temperature in summer may result an excessive premature death of the susceptible population (Kovats and Hajat, 2008). An increase of extreme temperature as well as longer heat wave observed with climate change would exacerbate premature death (McMichael et al., 2006; Peng et al., 2011; Wu et al., 2014). In cities, this increased mortality is boosted by the urban heat island effect. (Rey et al., 2009). Adaptation measures to heat waves are articulated around the development of effective heat health warning systems (Ebi et al., 2004; Kovats and Ebi, 2006; Lowe et al., 2011; Michelozzi et al., 2010; Pascal et al., 2006; Toloo et al., 2013). In the section, we are interested in testing the effect on mortality of mitigating the outdoor temperature with green roof in the city of Madrid.

The estimation of heat related death is challenging in several parameters of the heat-health relation. A challenge to estimate the premature death attributable to the heat event lies in the estimation of the threshold temperature above, which premature death is attributed to the heat event and not to natural death. Some studies have considered the temperature of minimum mortality, the turning point of the U-shape relation between temperature and death (Baccini et al., 2008; Gasparrini et al., 2015; Menne and Ebi, 2006; Watkiss and Hunt, 2011). Others studies refers to the threshold where mortality increases significantly in order to capture heat related death and not only temperature related death (Alberdi et al., 1998; Díaz et al., 2006, 2002; Fouillet et al., 2008). In the city of Madrid, the Heat health Warning System set the alert temperature at 36.5ºC based on epidemiological studies (Alberdi et al., 1998; Díaz et al., 2006, 2002).

From this threshold temperature will depend the calculation of the risk attributable to heat. In Madrid, the attributable risk has been estimated at 21.38%. This means that the daily premature death (all natural causes) increases by 21.38% when temperature increases by 1ºC above the threshold of 36.5ºC (Linares et al., 2014).

Under UHI reduction obtained from green roofs, the expected avoided mortality is the difference between the mortality due to heat with green roof and UHI reduction with the mortality due under no-UHI reduction. So, it also decomposes into a day effect and a temperature effect. The day effect occurs as the temperature reduction generated by green roofs reduces the number of days where the alert threshold temperature is exceeded. The temperature effect occurs as a lower temperature induces directly lower death from the attributable risk.

The value of statistical life (also value per statistical life) represents the individual willingness to pay for a small risk change, similar over the population in a finite time period divided the risk change or change in survival probability. It has a long history and grew with the needs to evaluate of public policies (Banzhaf, 2014). It is thus the monetary value of a mortality risk reduction that would prevent one statistical death and not one identified life[84] (Hammitt, 2000; Hammitt and Treich, 2007**)**. It measures in other words how much people are willing to pay to substitute wealth (money) for small risk reduction[85]. Whereas the VSL considers premature death (Banzhaf, 2014**)**, the Value of a Life Year (VOLY)[86] considers the change in life expectancy, i.e. a shift in the timing of death[87]. Desaigues et al. (2011) provides from a contingent valuation survey estimates of VOLY at EU scale. They found a VOLY of around 40.000EUR for 3 month life expectancy gain. Chilton at al. 2004 estimates a VOLY of (£2004) 7280 £ for 1 month of year life lost.

We followed OCED recommendations to transfer monetary valuation of VSL and VOLY in EUR, adjusted by consumer price index and income elasticity of 0.8. OECD recommends in the absence of specific studies the use of a VSL for EU27 of 3.6 m USD (2005 USD) with range of 1.8 and 5.4 m USD. We transfer this value to Spain. We apply the VSL to premature death and the VOLY estimated by Chilton at al. (2004) to the displaced mortality (those people that would have died whatever the climatic event in a short period of time). We estimated the displaced mortality rate around 40% (Davis et al., 2003; Hajat et al., 2005; Saha et al., 2013)**.**

[84] The controversy relative to the use of VSL in public policies evaluation for non-economists is thus rather a matter of inappropriate use of terminology (Banzhaf, 2014; Cameron, 2010). Value of preventing fatality is also used in the literature (Desaigues et al., 2011)

[85] For example, if an individual is willing to pay 4 EUR to reduce his chance of dying this year by two in a m, his VSL is four divided by 2 in a million, or 2 m EUR. So if each person in this population pays 4 EUR to reduce the chance of dying this year by two in a million, 2 m EUR would be paid and two life would be expected to be saved and the two beneficiaries would be unidentifiable.

[86] or Value per statistical life-year

[87] The main difference between VOLY and VSL approaches is that in a VSL approach each life saved is valued equally and in a VOLY approach it is valued in proportion to the life expectancy gain. However VOLY and VSL are linked as the VSL is the sum of the discounted flow of annual life year values.

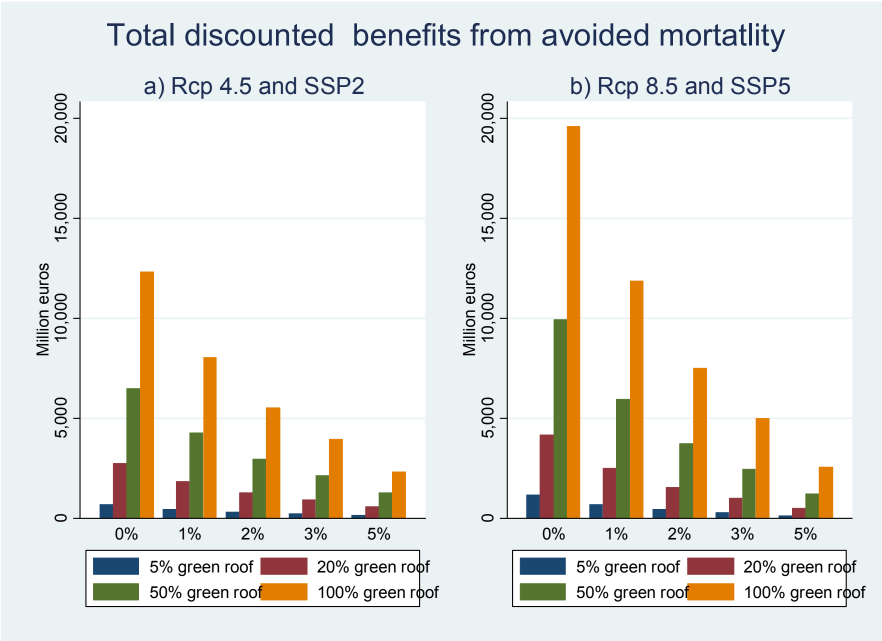



**Figure 6.16-5: Total discounted avoided mortality from green roof**

**Table 6.16-8: Total discounted benefits of $CO_2$ emission reduction services from green roofs for 2020-2100**

| | | | Discount rates | | | | |
|---|---|---|---|---|---|---|---|
| | | **Green roof coverage** | **0%** | **1%** | **2%** | **3%** | **5%** |
| **Climate change scenarios** | **SSP2 and Rcp45** | **5%** | 686 (134.4-1575.3) | 453.7 (89.9.-1041.2) | 315.3 (62-720.4) | 230.1 (43.9-521.1) | 139.9 (23.9-308.4) |
| | | **20%** | 2753.3 (412.3-6442.9) | 1825.9 (272-4270.1) | 1274.8 (188.6-2973.3) | 934.2 (137.2-2168.6) | 569 (82.9-1302) |
| | | **50%** | 6503.9 (1091.4-15556) | 4284.6 (719.4-10191) | 2961.1 (498.8-7005.9) | 2141.5 (362.8-5041.9) | 1262.6 (217.9-2948.2) |
| | | **100%** | 12335.7 (2148-28571) | 8052.4 (1423.6-18680) | 5518.4 (991.3-12819) | 3961.7 (723-9212.5) | 2311.2 (434.1-5381.8) |
| | **SSP5 and Rcp85** | **5%** | 1157.1 (247.4-3068.4) | 695 (153-1821.6) | 433.7 (97.3-1125.3) | 281.4 (63.9-725.5) | 133.6 (29.7-344.9) |
| | | **20%** | 4170.1 (691.5-10030) | 2491.7 (416-5987) | 1551.3 (260.5-3742) | 1009 (169.9-2457.4) | 489.2 (81.9-1229.9) |
| | | **50%** | 9954.9 (1723.6-24794) | 5961 (1033.1-15000) | 3735.3 (645.2-9505.2) | 2456.3 (421-6322.7) | 1229 (205.2-3233.4) |
| | | **100%** | 19621 (3343.9-47413) | 11863 (1996-28616) | 7512.4 (1247-18081) | 4993.4 (819-11988) | 2549 (410-6088.4) |

Notes: Low and high values in parentheses; Unit: m EUR.

**Benefits of green roof: water retention**

Green roofs influence the runoffs from rainfall: they delay the time where runoff will occur, reduce the total runoff, enlarge the temporal distribution of runoff as they give slower release of water (Berndtsson, 2010; Mentens et al., 2006). We will model the volume reduction services.

The rate of runoff is influenced by the roof type (slope of the roof, the depth of the substrate, the type of plant community) and the rainfall characteristics: distribution, intensity, duration (Berndtsson, 2010; Oberndorfer et al., 2007). The rainfall-runoff relation is also dependent on local climate characteristics. The quadratic estimation function of Mentens et al. (2006) for green roof is adapted to Western and Occidental European climate: this functional form is not relevant for drier climate. Simulation of this function for dry climate shows that runoffs from green roof would be higher than from non-green roof which contrary to expectations.

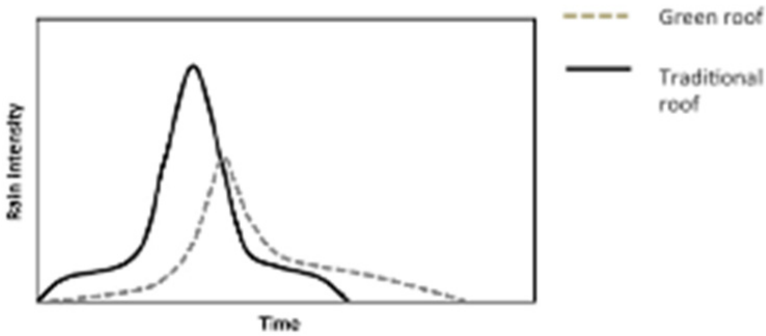



**Figure 6.16-6**
Source: Berndtsson (2010)

We review the performance of extensive green roofs on water management (Bengtsson et al., 2005; Bliss et al., 2008; Carter and Rasmussen, 2006; DeNardo et al., 2005; Fioretti et al., 2010; Getter et al., 2007; Hutchinson et al., 2003; Liptan, 2003; Liu and Minor, 2005; Mentens et al., 2006; Monterusso et al., 2005; Moran et al., 2005; Nardini et al., 2012; Razzaghmanesh and Beecham, 2014; VanWoert et al., 2005). Most of the papers of the literature refer to humid and continental climates. Regions of the world were runoff retention is challenging a priori due to the high precipitation. Very few refers to Mediterranean climate, only Razzaghmanesh and Beecham (2014).

**Table 6.16-9: Literature review of water retention coefficient of green roofs**

| Authors | Year | Country | City | Region | Köppen climate classification | Annual rainfall (mm) *** | Annual retention, % | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Low | Average | High |
| Mentens et al | 2006 | Belgium | | Brussels | Oceanic climate | 850 | | 54 | |
| Carter and Rasmussen | 2006 | US | Athens | Georgia | Humid subtropical | 1180 | 39 | 78 | 100 |
| Carter et al | 2008 | US | | Georgia | Humid subtropical | 1180 | | 77 | |
| Monterusso et al. | 2004 | US | | Michigan | Humid continental | 750-1000 | | 49 | |
| Getter et al | 2007 | US | | Michigan | Humid continental | 750-1000 | 75.3 | 80.2 | 85.2 |
| VanWoert et al | 2005 | US | | Michigan | Humid continental | 750-1000 | 50 | 61 | 98 |
| Moran et al. | 2005 | US | | North Carolina | Humid subtropical | 2000 | 55 | 59 | 63 |
| Hutchinson et al. | 2003 | US | | Oregon | Humid subtropical | 1000 | | 69 | |
| Liptan | 2003 | US | Portland | Oregon | Humid subtropical | 1000 | 59 | 69 | 92 |
| De Nardo et al. | 2005 | US | | Pennsylvania | Moderate continental | 1000 | 19 | 45 | 98 |
| Bliss et al | 2009 | US | | Pennsylvania | Moderate continental | 1000 | 5 | | 70 |
| Bengtsson et al. | 2005 | Sweden | Malmö | South | Temperate humid climate | 600 | | 46 | |
| Liu | 2005 | Canada | Toronto | Ontario | Humid continental | 830 | | 57 | |
| Nardini et al | 2008 | Italy | Trieste | Friuli–Venezia Giulia | Humid subtropical | 1000 | 63.3 | 81.9 | 90.5 |
| Fioretti et al (**) | 2010 | Italy | Genova | Liguria | Humid subtropical | 1000 | 15 | 98 | 100 |
| Razzaghmanesh and Beecham | 2014 | Australia | Adelaide | South | Mediterranean | 550 | 66 | 74 | 81 |
| Beecham and Razzaghmanesh | 2015 | Australia | Adelaide | South | Mediterranean | 550 | 52 | 73* | 95 |

Notes: *calculated, ** Although Fioretti's title refers to Mediterranean climate, we consider Genova as Humid subtropical. *** Source: Wikipedia

We use the values of retention of a **Mediterranean climate, similar to the climate of Madrid**. For traditional roof, we used 8%, 10% and 13% for the water retention coefficient (Carpenter and Kaluvakolanu, 2011; Mentens et al., 2006).

Although it has been shown that the water retention capacity decreases the intensity of rainfall (Carpenter and Kaluvakolanu, 2011), we consider a constant water retention capacity since our climate data do not inform on the daily pattern of rainfall.

Given that green roof delay the time where runoff will occur, reduce the total runoff, enlarge the temporal distribution of runoff, we could consider that the water retained by green roof is water that is not going to the sewer system and thus does not need to be treated by the water utility. Given the property right of data on real cost of water treatment, we use the price paid by users for water treatment in Madrid. In 2011, this price is 0.63 EUR/m3 for sanitation and purification services. The benefits of green roof for the water retention service is therefore measured in terms of avoided water treatment cost. Table 6.16-10 gives the water retention under the different scenario, estimated in % of total rainfall over all the area of the city. For a 20% green roof coverage it varies from 4.4% to 6.5%

per year on average over 2020-2100. There is no distinction between RCPs when the water retention is measured in percentage of rainfall.

**Table 6.16-10: Percentage of overall rainfall retained by green roofs under climate change scenarios**

| | RCP 4.5 | | RCP8.5 | |
|---|---|---|---|---|
| **Green roofs coverage** | **Average retention percentage of total rainfall over Madrid area, 2020-2100, %** | **Range: Low-high, %** | **Average retention percentage of total rainfall over Madrid area, 2020-2100, %** | **Range: Low-high, %** |
| **5%** | 1.39 | 1.11 - 1.63 | 1.39 | 1.11 - 1.63 |
| **20%** | 5.57 | 4.44 - 6.52 | 5.57 | 4.44 - 6.52 |
| **50%** | 13.92 | 11.09 - 16.31 | 13.92 | 11.09 - 16.31 |
| **100%** | 27.83 | 22.18 - 32.62 | 27.83 | 22.18 - 32.62 |

Note: The difference between Rcp4.5 and Rcp8.5 does not appear when average percentage are computed.

We present the benefits for SSP2 and RCP4.5 and for SSP5 and RCP8.5 below. For a given discount rate, the benefits increase with the share of green roof coverage over Madrid. With a 2% discount rate, the benefits vary from 57.5 m EUR with a 5% rate of green roof coverage to 1149 m EUR for a total coverage in the climate scenario Rcp4.5 and SSP2. We also observe that benefits are higher in the low mitigation scenario (Rcp8.5) given that precipitation projections give higher rainfall for this scenario. Benefits are also higher in the socio-economic scenario SSP5 than in the socio-economic scenario SSP2, given their respective GDP per capita trends.

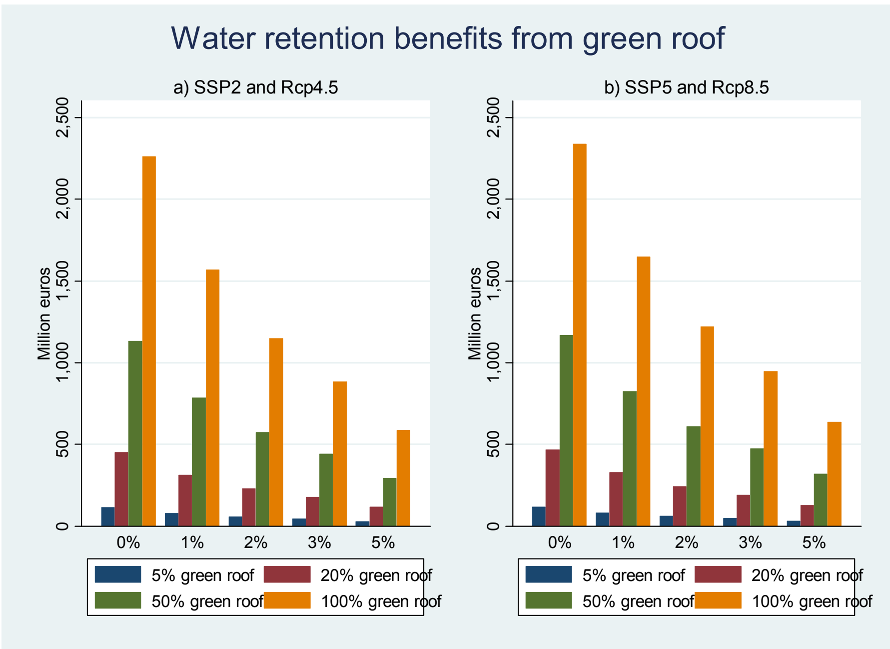



**Figure 6.16-7: Total discounted benefits of average water retention services for 2020-2100**

**Table 6.16-11: Total discounted benefits in m EUR of water retention services for 2020-2100.**

| | | | Discount rates | | | | |
|---|---|---|---|---|---|---|---|
| | | Green roof coverage | 0% | 1% | 2% | 3% | 5% |
| Climate change scenarios | SSP2 and Rcp45 | 5% | 113.5 (90.1-132.5) | 78.4 (62.5-91.91) | 57.5 (45.8-67.3) | 44.2 (35.2-51.8) | 29.4 (23.4-34.4) |
| | | 20% | 452.2 (360.4-529.9) | 313.7 (250-367.6) | 229.9 (183.2-269.4) | 176.8 (140.9-207.2) | 117.5 (93.6-137.7) |
| | | 50% | 1130.5 (900.9-1324.8) | 784.3 (625-919.1) | 574.9 (457.9-673.4) | 442 (352.2-673.4) | 293.8 (234.1-344.2) |
| | | 100% | 2261.1 (1801.8-2649.7) | 1568.6 (1250-1838.2) | 1149.4 (915.9-1346.9) | 884.1 (704.5-1036) | 587.5 (468.2-688.5) |
| | SSP5 and Rcp85 | 5% | 117 (93.2-137.1) | 82.3 (65.6-96.5) | 61 (48.6-71.5) | 47.4 (37.7-55-5) | 31.8 (25.4-37.3) |
| | | 20% | 467.9 (372.9-548.3) | 329.3 (262.4-385.9) | 244.1 (194.5-286.1) | 189.4 (151-222) | 127.3 (101.4-149.2) |
| | | 50% | 116.8 (932.2-1370.8) | 823.2 (656-964.7) | 610.3 (486.3-715.2) | 473.6 (377.4-555) | 318.2 (253.6-372.9) |
| | | 100% | 2339.5 (1864.3-2741.6) | 1646.5 (1312-1929.5) | 1220.5 (972.6-1430.3) | 947.2 (754.8-1110) | 636.4 (507.2-745.8) |

Notes: Low and high values in parentheses; Unit: m EUR.

**Benefits of green roof: reduction of maintenance**

We consider a 30 years lifespan for the green roof and a renovation of the roof after the age. For traditional roofs we use a 20 years lifespan. Therefore at horizon 2099, the renovation of the traditional roof in 2060 can be avoided if the building is constructed with a green roof. The benefit of green roof is thus estimated as an avoided renovation cost due to lifespan gain.

**Table 6.16-12: Total discounted benefits of life span gain from green roofs**

| | | | Discount rates | | | | |
|---|---|---|---|---|---|---|---|
| | | Green roof coverage | 0% | 1% | 2% | 3% | 5% |
| Climate change scenarios | SSP2 and Rcp45 | 5% | 308 (247.4-368.6) | 206.9 (166.2-247.6) | 139.5 (112.1-166.9) | 94.4 (75.9-113) | 43.8 (35.1-52.4) |
| | | 20% | 1232.1 (989.7-1474.5) | 827.6 (664.8-990.4) | 558 (448.2-667.8) | 377.7 (303.4-452) | 175 (140.6-209.4) |
| | | 50% | 3080.3 (989.7-3686.3) | 2068.9 (664.8-2475.9) | 1395 (448.2-1669.5) | 944.3 (303.4-1130.1) | 437.5 (140.6-523.6) |
| | | 100% | 6160.6 (4948.7-7372.5) | 4137.8 (3323.8-4951.8) | 2790.1 (2241.2-3338.9) | 1888.6 (1517.1-2260.1) | 875.1 (702.9-1047.2) |
| | SSP5 and Rcp85 | 5% | 316.7 (254.4-379.1) | 212.7 (170.9-254.6) | 143.5 (115.2-171.7) | 97.1 (78-116.2) | 45 (36.1-53.8) |
| | | 20% | 1267 (1017.7-1516.2) | 851 (683.6-1018.4) | 573.8 (460.9-686.7) | 388.4 (312-464.8) | 180 (144.6-215.4) |
| | | 50% | 3167.5 (1017.7-3790.6) | 2127.5 (683.6-2546) | 1434.5 (460.9-1716.7) | 971 (312-1162) | 449.9 (144.6-538.4) |

Notes: Low and high values in parentheses; Unit: m EUR.

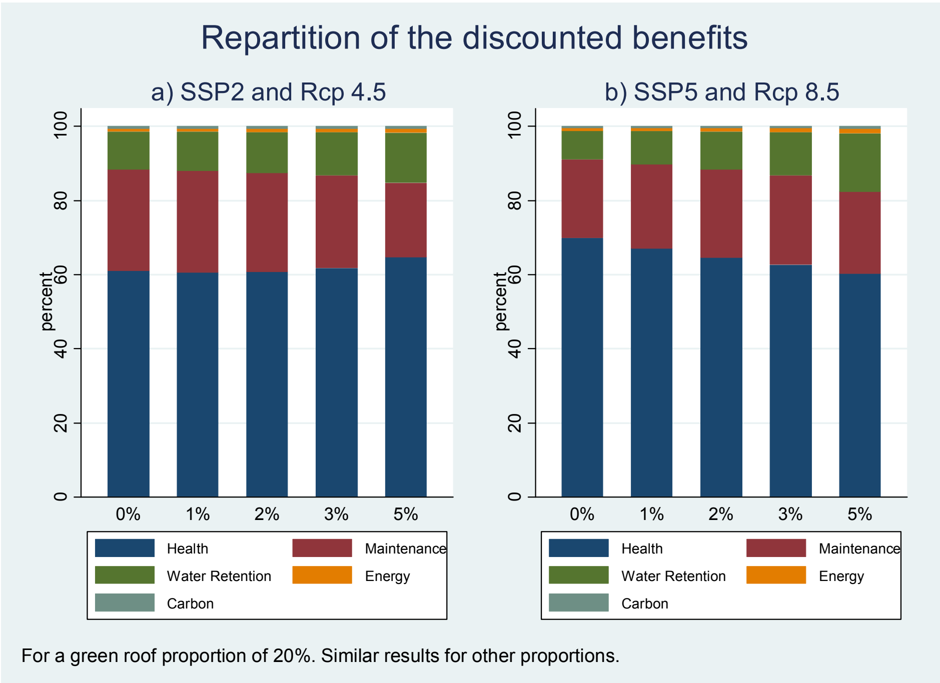



**Figure 6.16-8: Repartition of the 5 types of benefits for the different discount rates and socio-climatic scenarios**

Under the specified services valuation assumptions, around 60% of the benefits from green roofs are due to the avoided deaths obtained from the reduction of outdoor temperature, 20% from the reduction in the maintenance costs and about 15% from water retention. Energy savings and carbon footprint reduction are negligible.

**Heat health watch warning system in Madrid**

In a changing climate heatwaves will pose an increased threat to human health especially in urban areas and among vulnerable groups. To mitigate these impacts, heat health watch warning systems (HHWWS) are usually set up to warn the population, give early alerts, advisories and emergency measures to mitigate the impact of a heat wave. A heat warning alert is usually triggered when climatic variables exceed specified criteria, which might include daily maximum temperature, relative humidity, among others, which can be used to define a cut-off temperature when excess mortality is expected to increase rapidly. The choice of the cut-off temperature is therefore an essential parameter if a HHWWS is to be operated effectively as a counter-measure (adaptation) to reduce the heat-related health impacts in the context of a changing climate in which the frequency, intensity and duration of heat waves is expected to increase in the coming decades. In the future, local governments in urban areas that currently are not faced with severe heat events will have to consider, outline, fund and execute contingency plans to protect its citizens against the increased risks posed by climate change. Not only is the climate changing, but also urban morphology will likely exacerbate the potential severity of the health impacts. Therefore, knowledge of this critical temperature and more importantly how it might vary over space and time due to climatic parameters, socioeconomic conditions, population health status, and people's behavioural responses to a changing environment will have a profound influence on the effectiveness of prevention measures, including the efficacy of a HHWWS.

In the case study for Madrid, we conducted a cost-benefit analysis of the HHWWS to analyse the long-term costs and benefits (2020-2100) of running the system under different climate scenarios and to identify the additional costs of implementation if acclimatisation processes are not properly considered (in terms of changing critical temperature, attributable risk on health and displaced mortality ratio).

In order to estimate the health risks and the critical temperature (Tcrit) defining an episode of heatwaves, an epidemiological study was carried out in collaboration with the Instituto Carlos III (Cristina Linares Gil, Rocío Carmona Alférez, Julio Díaz Jiménez, Escuela Nacional de Sanidad, September 2014). In this study we found that in the period 2001-2009 the Tcrit has decreased to 34 °C compared to the period 1986-1997, in which this temperature was established at 36.5°C. Nevertheless, the current HHWWS is set up on the temperature of 36.5°C, which implies a loss of health benefits, which would be otherwise observed if the system were launched at the new threshold.

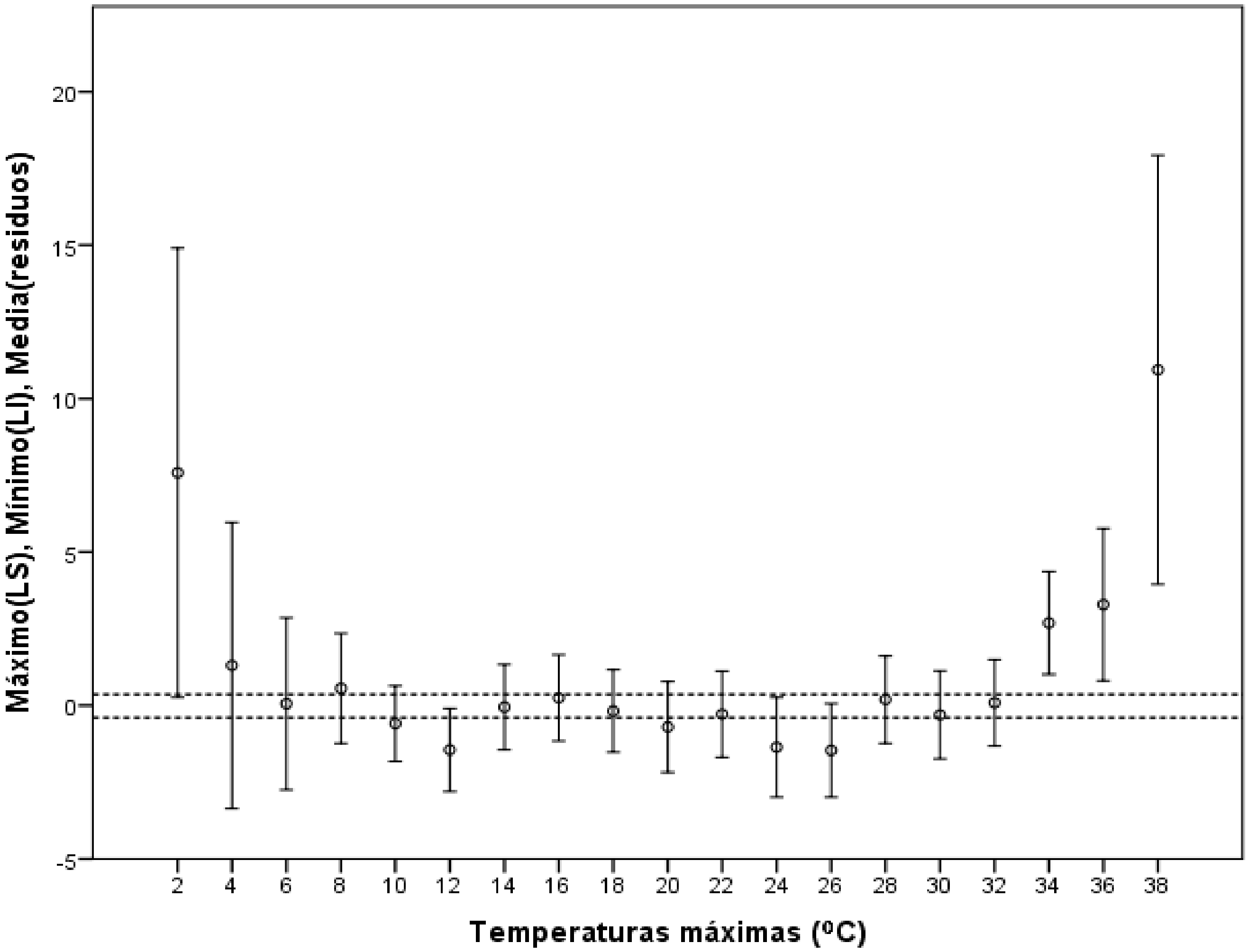
We present here below the assumptions behind the baseline and projection scenarios for the time span 2020-2100, and afterwards the results in terms of economic costs, physical and economic benefits, cost-benefit ratios (BCR) and differences in costs and benefits when running the system without taking into account the correct set up of Tcrit over time.

**Scenarios**

*Baseline scenario*

The notion of threshold or critical temperature (Tcrit) is crucial in the definition of a HHWWS. This is the temperature above which the daily mortality is expected to start increasing significantly. Health risks and Tcrit have been estimated for the years 2001-2009 by Diaz et al (2014a) specifically for the case study of Madrid. Table 6.16-13 shows the maximum daily temperature and mortality residuals to define a heatwaves episode in Madrid. As it can be seen from the figure, mortality residuals start to increase significantly at the temperature of 34°C, instead of 36.6°C at which the current HHWWS for Madrid is set up.

**Table 6.16-13: Maximum daily temperature and mortality residuals in Madrid**




Source: Diaz et al (2014a)

Diaz et al (2014a) estimated also the health risks (as attributable risks AR) associated with heatwaves (in terms of increased mortality all causes, cardiovascular and respiratory, for all ages and for different age groups). AR is defined as the percentage increase in daily mortality attributable to heatwaves, for each degree centigrade where the maximum temperature is above Tcrit (Diaz et al, 2014a). Table 6.16-14 presents RR and AR related to daily mortality attributable to heatwaves. The AR estimated is equal to 4.24% for each degree increase in maximum temperature above the threshold.

**Table 6.16-14: Variations in relative risk (RR) and attributable risk (AR) related to daily mortality caused by heat waves.**

| | Variable | RR | IC 95% | | RA(%) | IC 95% | |
|---|---|---|---|---|---|---|---|
| Total causas naturales (CIE-10: A00-R99) | | | | | | | |
| Todo el año (N= 2149) | $PM_{2.5}$ (lag 2) | 1,008 | 1,000 | 1,016 | 0,83 | 0,04 | 1,61 |
| | Tcal (lag 2) | 1,022 | 1,008 | 1,036 | 2,15 | 0,79 | 3,47 |
| | Tfrio (lag 1) | 1,039 | 1,008 | 1,072 | 3,77 | 0,75 | 6,70 |
| | Tfrio (lag 7) | 1,045 | 1,016 | 1,075 | 4,33 | 1,56 | 7,01 |
| | $NO_2$ (lag 1) | 1,007 | 1,003 | 1,010 | 0,67 | 0,31 | 1,02 |
| | Olea (lag 1)* | 1,003 | 1,000 | 1,005 | 0,25 | -0,02 | 0,52 |
| | Tasa Gripe(lag 1) | 1,005 | 1,004 | 1,006 | 0,52 | 0,41 | 0,63 |
| | Leq24 (lag 0) | 1,018 | 1,014 | 1,022 | 1,75 | 1,37 | 2,14 |
| Verano (N=732) | $PM_{2.5}$ (lag 0) | 1,022 | 1,005 | 1,040 | 2,16 | 0,47 | 3,81 |
| | Tcal (lag 1) | 1,023 | 1,008 | 1,037 | 2,22 | 0,84 | 3,58 |
| | Tcal (lag 3) | 1,021 | 1,007 | 1,034 | 2,02 | 0,73 | 3,30 |
| | Leq24 (lag 0) | 1,018 | 1,011 | 1,025 | 1,77 | 1,06 | 2,47 |
| | Leqn (lag 3) | 1,006 | 1,001 | 1,011 | 0,61 | 0,10 | 1,12 |
| Invierno (N=907) | $PM_{2.5}$ (lag 1) | 1,021 | 1,006 | 1,009 | 2,10 | 0,64 | 0,87 |
| | Tfrio (lag 1) | 1,038 | 1,010 | 1,066 | 3,62 | 1,00 | 6,16 |
| | Tfrio (lag 7) | 1,044 | 1,017 | 1,073 | 4,25 | 1,65 | 6,79 |
| | Tfrio (lag 11) | 1,029 | 1,001 | 1,057 | 2,77 | 0,10 | 5,37 |
| | Tasa Gripe(lag 0) | 1,001 | 1,001 | 1,001 | 0,08 | 0,06 | 0,09 |
| | Leqd (lag 0) | 1,007 | 1,003 | 1,011 | 0,68 | 0,31 | 1,05 |
| | Leq24 (lag 1) | 1,010 | 1,003 | 1,017 | 1,00 | 0,35 | 1,64 |
| | Leq24 (lag 3) | 1,007 | 1,000 | 1,013 | 0,65 | 0,03 | 1,26 |

Source: Diaz et al (2014a)

Diaz et al (2014b) estimated that the majority of deaths would occur for people older than 74. In our case study we distinguish between two mortality effects: premature and displaced mortality. Premature mortality refers to people in normal health who would die because of the heatwaves, while displaced mortality concerns people already in poor health (for example because of pre-existing cardio-vascular or respiratory problems) who would die in the short term anyway, regardless of the heatwaves. Displaced mortality refers therefore to a shift in mortality rate, and it is also known as harvesting effect. According to our estimates, for people in poor health the heatwaves episode would shorten their life expectancy between one week and one month (assuming a lognormal distribution). The mean loss of life, calculated over the period 2020-2100 is about 16 days per death. For premature mortality, the loss of life expectancy has been estimated between 6 months (which increases to 1 year by 2100) and the remaining life expectancy at the age of the death (assuming a lognormal distribution). The mean loss of life over 2020-2100 is about 4.7 years per premature death. Life years loss calculations account for time changes in life expectancy as a function of age group, future changes in demographics (cohort shares), and distribution of heat deaths (both premature and displaced) among cohort classes. Displaced mortality rate has been set up at 40% and 65% (Hajat et al, 2005), and the rate of 40% has been used for carrying out the CBA.

For our calculations, the baseline scenario is constructed over the period 2004-2009. We chose this time frame as the HHWWS was established in 2003.

*Projection scenarios (2020-2100)*

Having established the appropriate Tcrit for the baseline, we have constructed the following scenarios to project the costs and benefits of the HHWWS by the end of the century (2100):

RCP4.5, SSP2

- Scenario 1 (S1): no acclimatisation, Tcrit (34°C), attributable risk (AR=4.24%) and displaced mortality ratio (DMR=40%) constant over time.
- Scenario 1a (S1a): with acclimatisation, Tcrit, attributable risk (AR) and displaced mortality ratio (DMR) changing over time.

RCP8.5, SSP5

- Scenario 2 (S2): no acclimatisation, Tcrit (34°C), attributable risk (AR=4.24%) and displaced mortality ratio (DMR=40%) constant over time.
- Scenario 2a (S2a): with acclimatisation, Tcrit, attributable risk (AR) and displaced mortality ratio (DMR) changing over time.

*Critical temperature* in the baseline scenario is set up at 34°C as estimated in Diaz et al (2014a) for the period 2004-2009. We expect the Tcrit to increase over time due to an effect of: physical acclimatisation (the number of deaths due to heat is higher at the beginning of the summer than at the end), adaptation measures (such as emergency systems, medical assistance or green infrastructures) and behavioural changes (because of improved information).

The projected evolution of Tcrit in the acclimatisation scenarios between 2020 and 2100 is based on a probability density function elaborated on projections of future daily maximum temperatures provided by CMCC. Tcrit has a "hockey-stick" shape with varying threshold values and approximate linear behaviour thereafter. The short and long lag curves coincide with the 95% CI of Tcrit by the end of the century. The line identifies the annual mean Tcrit temperature of the random, stepwise Tcrit trajectories assumed in the Monte Carlo simulations.

A HHWWS is a low regret urban adaptation option to climate change, and consequently, highly relevant for decision-making. The HHWWS usefulness depends on the correct specification of Tcrit. Current long-term studies of heatwaves impacts assume constant Tcrit, but decadal variations of Tcrit have been reported in Castilla-La Mancha, Spain (BASE). Failure to recognize time-dependence of Tcrit is likely to render HWWS, and other urban adaptation measures, inefficient, and potentially cost-ineffective.

Figure 6.16-9 and Figure 6.16-10 show the evolution of Tcrit (medium lag) for RCP4.5 and 8.5.

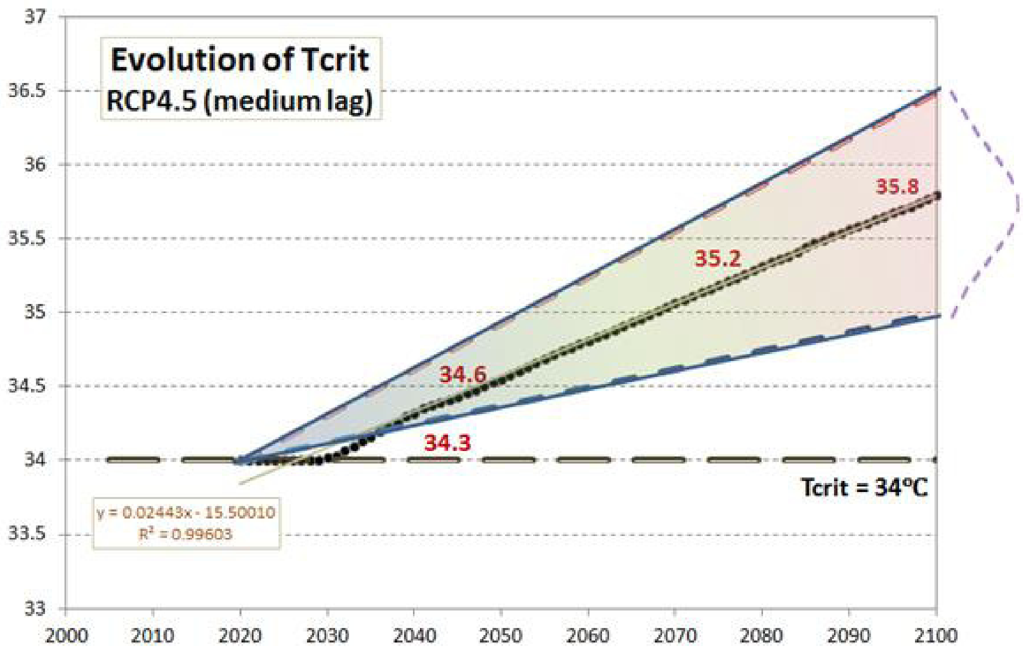


Figure 6.16-9: projected evolution of Tcrit (°C) between 2020 and 210 for scenario RCP4.5

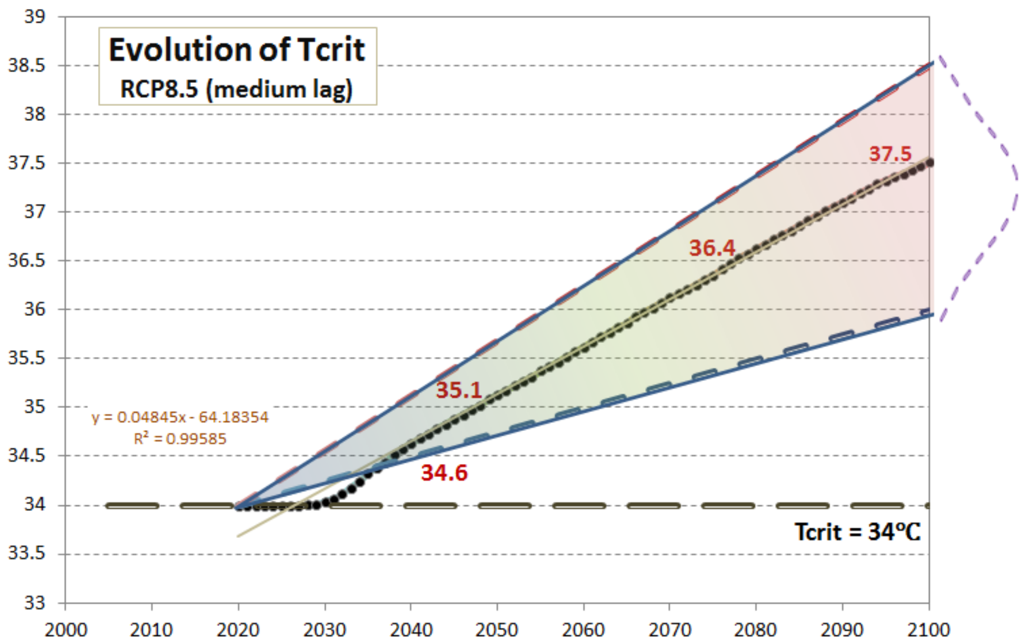


Figure 6.16-10: projected evolution of Tcrit (°C) between 2020 and 210 for scenario RCP8.5

The potential scenarios of *attributable risk* evolution for Madrid over the period 2020-2100 are shown in Figure 6.16-11considering a scenario of acclimatization where Tcrit is changing over time. AR can be estimated as a function of Tcrit over time: $RA$=0.016342 $T_{crit}$−0.51322 (mean curve)

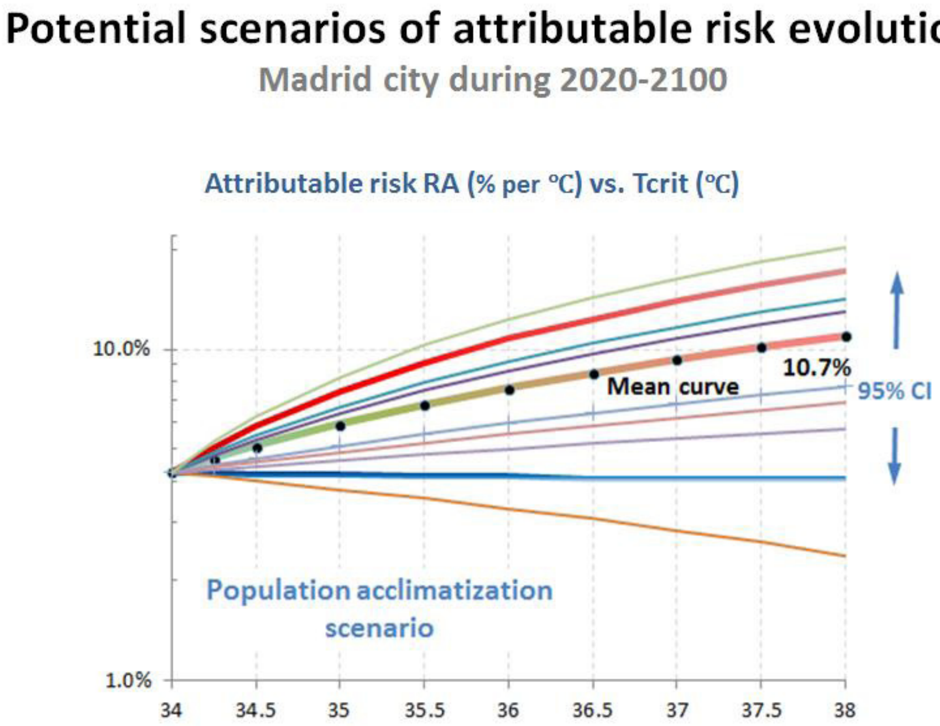



**Figure 6.16-11: Evolution of attributable risk with changing Tcrit.**

Finally, as regards the *displaced mortality rate* (DMR), this is assumed to decrease over time when Tcrit is increasing. Figure 6.16-12 and Figure 6.16-13 show the projected evolution of DMR as a function of Tcrit over the period 2020-2100.

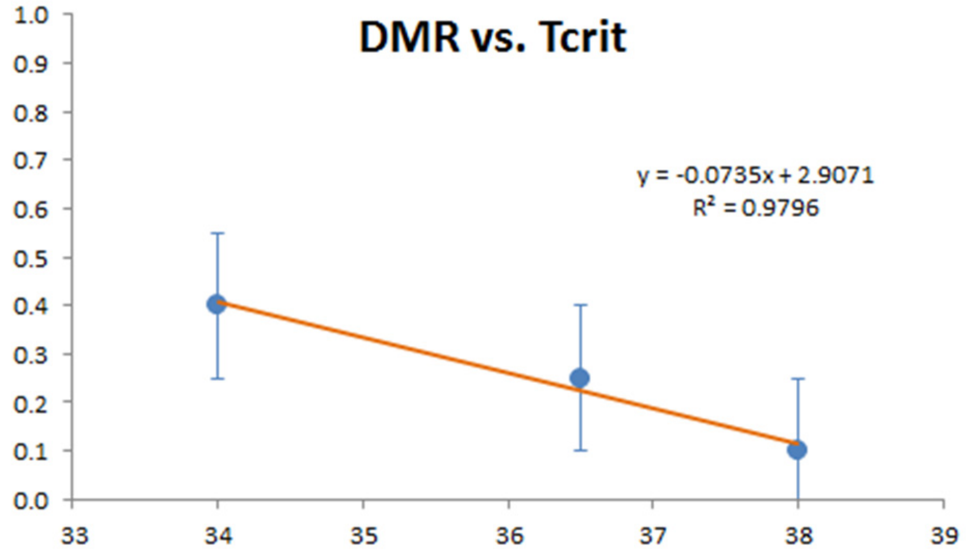



**Figure 6.16-12: Evolution of DMR as a function of Tcrit (40% in 2020)**

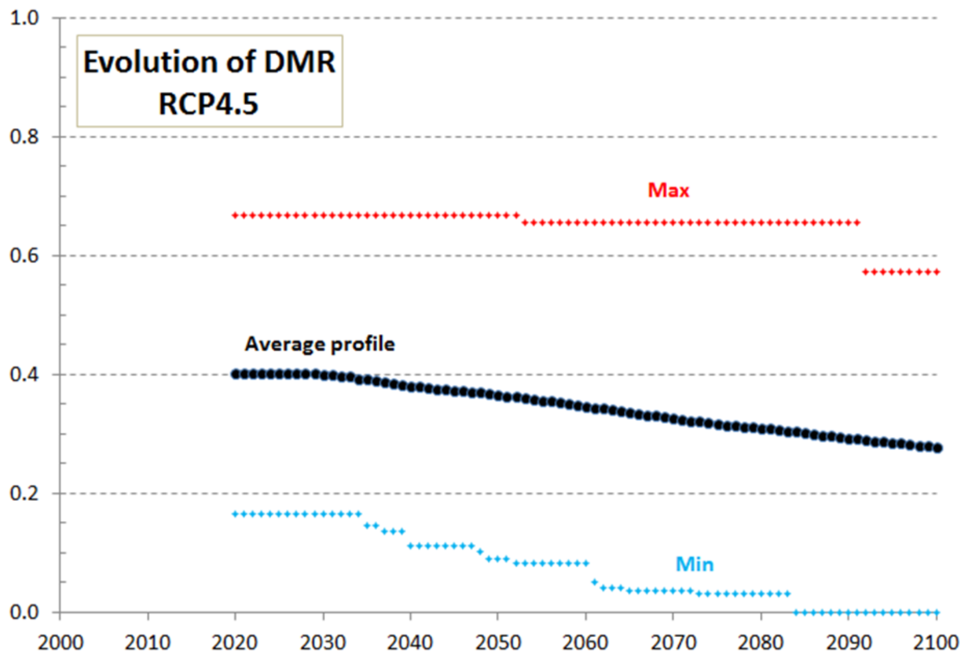



**Figure 6.16-13: Projected evolution of DMR in the period 2020-2100**

In the next sections we present the estimation of the costs and benefits related to the HHWWS under the baseline and projection scenarios, together with the BCR.

**Costs**

Total annual costs of the HHWWS are related to the number of days of alert (the days in which the maximum temperature is expected to be above Tcrit), which depends on the Tcrit and differs in the climate scenarios RCP 4.5 and 8.5.

Total annual cost = Cost per day of alert * Number of days of alert (L)

The unit costs used for the HHWWS of Madrid are based on two references, Ebi et al. (2004) for the variable costs and personal interviews to stakeholders in Madrid for the fixed cost of the heatline.

Cost of heatline:

- Fixed costs of maintenance of the system: 500 EUR per year (2013 EUR/yr.) (personal communication with Health Department of Madrid Salud),
- Variable costs due to personal (average): 3,375 EUR/day (2013 EUR/day) (750-6,000 EUR/day, adapted from Ebi et al, 2004).

Total implementation costs of the system depend on the number of days in which the HHWWS is activated, which is the number of days in which the maximum temperature exceeds the critical stated threshold. For Madrid, the epidemiological study of Diaz et al (2014a) found that in the period 2001-2009 the Tcrit has decreased to 34 °C compared to the period 1986-1997, in which this temperature was established at 36.5°C. Nevertheless, the current HHWWS is set up on the temperature of 36.5°C, which implies a loss of health benefits, which would be otherwise observed if the system were launched at the new threshold.

We present here below the total costs of HHWWS projected costs 2100, as well as the additional costs that would be supported if the Tcrit is not correctly set up taking into account the acclimatisation process.

*Projections of costs to 2100*

Table 6.16-15 and Table 6.16-16 show the discounted costs of implementation of the HHWWS in the two scenarios: with acclimatization and without acclimatization, for three estimates of the unit cost (low, medium and high).

**Table 6.16-15: Total discounted costs of HHWWS in Madrid for period 2020-2100**

| S1 - no acclimatisation, Tcrit constant=34 | d=0 | d=1 | d=2 | d=3 | d=5 |
|---|---|---|---|---|---|
| HHWScost=low | 2.01 | 1.35 | 0.95 | 0.71 | 0.44 |
| HHWScost=avg | 8.90 | 5.96 | 4.21 | 3.13 | 1.96 |
| HHWScost=high | 15.80 | 10.58 | 7.48 | 5.56 | 3.48 |
| **S1a - acclimatisation, Tcrit increasing** | **d=0** | **d=1** | **d=2** | **d=3** | **d=5** |
| HHWScost=low | 1.62 | 1.12 | 0.82 | 0.62 | 0.41 |
| HHWScost=avg | 7.13 | 4.94 | 3.61 | 2.76 | 1.80 |
| HHWScost=high | 12.65 | 8.76 | 6.40 | 4.89 | 3.20 |

Notes: RCP4.5, SSP2, M EUR2013

**Table 6.16-16: Total discounted costs of HHWWS for period 2020-2100**

| S2 - no acclimatisation, Tcrit constant=34 | d=0 | d=1 | d=2 | d=3 | d=5 |
|---|---|---|---|---|---|
| HHWScost=low | 2.70 | 1.74 | 1.18 | 0.85 | 0.51 |
| HHWScost=avg | 12.00 | 7.71 | 5.25 | 3.77 | 2.25 |
| HHWScost=high | 21.30 | 13.69 | 9.31 | 6.69 | 4.00 |
| **S2a - acclimatisation, Tcrit increasing** | **d=0** | **d=1** | **d=2** | **d=3** | **d=5** |
| HHWScost=low | 1.70 | 1.15 | 0.82 | 0.62 | 0.40 |
| HHWScost=avg | 7.50 | 5.06 | 3.62 | 2.74 | 1.79 |
| HHWScost=high | 13.30 | 8.97 | 6.42 | 4.86 | 3.17 |

Notes: RCP8.5, SSP5, M EUR2013.

If the evolution of Tcrit is not taken into account when running the HHWWS, the society would incur in additional costs of implementation of the system when it is not necessary (because there is no additional expected mortality due to heatwaves). Table 6.16-17 shows the additional costs of running the HHWWS at the wrong temperature for RCP4.5 and 8.5 (assuming the discount rate equal to 0), and not taking into account a variation of AR and DMR. The economic loss would range from 25% to 60% increase in the costs of implementation. The costs are higher in RCP8.5 due to the higher number of days of alert as well as to the increased costs under SSP5. For the exemplification, we consider average values for the HHWS effectiveness.

**Table 6.16-17: Additional costs for running the HHWWS with incorrect Tcrit for period 2020-2100**

| | Ndays | Cost HHWS (avg, M€2013) |
|---|---|---|
| **RCP4.5** | | |
| S1 | 2,456 | 8.90 |
| S1a | 1,957 | 7.13 |
| Additional costs | 25% | 25% |
| **RCP8.5** | | |
| S2 | 3,243 | 12.00 |
| S2a | 2,011 | 7.50 |
| Additional costs | 61% | 60% |

Notes: M EUR 2013, d=0 (average costs)

**Benefits**

*Estimation of health impacts*

The benefits associated with the HHWWS are the avoided deaths or the increased life expectancy in term of life years. The expected mortality due to heat wave is calculated as follows:

$$EM_{\bar{t}} = RA_{\bar{t}} \times \mu \times \Delta T_{\bar{t}} \times L_{\bar{t}}$$

Where $EM_{\bar{t}}$ the expected mortality for the Tcrit $\bar{t}$, $RA_{\bar{t}}$ is the attributable risk for Tcrit $\bar{t}$, $\mu$ is the average daily mortality for all causes for the whole population calculated during the heatwaves, $\Delta T_{\bar{t}}$ is the excess temperature above the Tcrit $\bar{t}$ and $L_{\bar{t}}$ is the number of days above Tcrit $\bar{t}$. The expected premature mortality is calculated by subtracting the displaced mortality rate:

$$PEM_{\bar{t}} = RA_{\bar{t}} \times \mu \times \Delta T_{\bar{t}} \times L_{\bar{t}} \times (1 - DMR)$$

Similarly, for estimating the total years of life lost (LYL):

$$PLYL_{\bar{t}} = RA_{\bar{t}} \times \mu \times \Delta T_{\bar{t}} \times L_{\bar{t}} \times PLLE_{\bar{t}}$$

$$DLYL_{\bar{t}} = RA_{\bar{t}} \times \mu \times \Delta T_{\bar{t}} \times L_{\bar{t}} \times DLLE_{\bar{t}}$$

Where *PLLE* is the loss of life expectancy per death for premature mortality and *DLLE* is the loss of life expectancy per death for displaced mortality.

$$TOTLYL_{\bar{t}} = PLYL_{\bar{t}} + DLYL_{\bar{t}}$$

In order to compute the total deaths (*AM*), which could be avoided through the HHWS, we multiply the above expected mortality (or *LYL*) by the effectiveness (*E*) of the HHWWS as estimated by Fouillet et al, 2008 (avg=68%, low=60%, high=76%).

$$AM_{\bar{t}} = EM_{\bar{t}} \times E$$

Table 6.16-18 presents the health impacts (in terms of total deaths as well as LYL, both for premature and displaced mortality) for RCP4.5 and 8.5 with and without acclimatisation. The scenarios of acclimatisation (S1a and S2a) include a variation not only of Tcrit, but also of AR and DMR over time.

**Table 6.16-18: Health impacts under different climate scenarios**

| Scenario | Tot deaths | Premature deaths | Tot LYL | Premature LYL | Displaced LYL |
|---|---|---|---|---|---|
| **RCP4.5** | | | | | |
| S1 | 20,410 | 12,246 | 57,915 | 57,557 | 358 |
| S1a | 18,447 | 12,107 | 57,179 | 56,901 | 278 |
| | (-9.6%) | (-1.1%) | (-1.3%) | (-1.1%) | (-22.3%) |
| **RCP8.5** | | | | | |
| S2 | 33,168 | 19,901 | 94,115 | 93,533 | 582 |
| S2a | 26,756 | 20,561 | 96,908 | 96,636 | 272 |
| | (-19.3%) | (+3.3%) | (+3%) | (+3.3%) | (-53.3%) |

Notes: DMR 40% and decreasing over time.

In a scenario of acclimatisation (as defined by a variation of Tcrit, AR and DMR) total deaths are reduced by 9.6% (RCP4.5) and 19.3% (RCP8.5). Over time, however, AR increases while DMR decreases, both effects contributing to an increase in the number of projected premature deaths under the acclimatisation scenario in RCP8.5.

In RCP4.5 the health benefits are lower in a scenario of acclimatisation using any of the proposed health indicators. As expected, this is due to a decrease in the number of days in which maximum daily temperature is higher than Tcrit, which indicates a decrease in people vulnerability. Though with acclimatisation there is an increase of AR and a decrease in DMR on average, these effects are lower than the decrease in Ndays. In RCP8.5, however, the effects of AR and DMR variation over time are much larger than the decrease in Ndays, which entails an increase in the number of premature deaths and LYL over time.

For the CBA, we evaluate the health benefits using premature and displaced LYL and VOLY estimates, in order to provide a lower bound of the economic benefits. Using the number of deaths and VSL would increase considerably the economic benefits.

*Monetisation of the health impacts*

For the monetisation of the health impacts, two measures can be used: the Value of Statistical Life (VSL) or the Value of a Life Year (VOLY). For the case study, we decided to use the following values and scenarios for the health economic valuation:

- VSL for all deaths (OECD, 2011).
- VSL only for premature deaths (OECD, 2011).
- VSL (OECD, 2011) only for premature deaths and no value for displaced mortality (following OECD guidelines, and considering that there is some evidence in the literature that respondents give no value to a gain in life expectancy in poor health (Chilton et al, 2004, found that more than half of the respondents interviewed stated zero WTP for small changes in life expectancy is in poor health).
- VOLY for premature mortality (de Ayala and Spadaro, 2014) and VOLY (Chilton et al 2004) for displaced mortality.

The values for VSL suggested by OECD (2011) range from 1.8 to 5.4 m US$ 2005 for all Europe. The values for VOLY proposed by Chilton et al (2004) for DEFRA refer to both normal and poor health, and for 1, 3 and 6 months gain in life expectancy in a context of air pollution. Their values are reported in Table 6.16-19 below. We use these values for one month gain in poor health as the estimated gain in life expectancy for Madrid ranges from one week to one month, so that we think that the values proposed by Chilton for acute mortality are the most appropriate if we want to monetize this small benefit.

**Table 6.16-19: VOLY**

| | Normal health | Poor health |
|---|---|---|
| 1 month sample | 27,630 | 7,280 |
| 3 months sample | 9,430 | 1,600 |
| 6 months sample | 6,040 | 1,290 |

Note: £2004
Source: Chilton et al. (2004)

Finally, for premature mortality we use the VOLY estimated by de Ayala and Spadaro (2004) adjusted for VSL/VOLY chronic impacts. Original values have been adjusted following OECD guidelines (2011) taking into account:

- Conversion to national currencies (PPP-adjusted exchange rates)
- Domestic Consumer Price Index (CPI) for adjust to the current prices in individual countries
- Income adjustment in individual countries (in terms of GDP per capita) from the study site to the policy site (using 0.8)
- Correction of increased real income in time

Table 6.16-20, Table 6.16-21 and Table 6.16-22 show original and adjusted values in Euro2013 (under different assumptions of income elasticity over space and time). For the CBR in our case study, we use an elasticity of 0.8 for adjustment over space, and 1 for adjustment over time. For sensitivity analysis, the values reported in the tables below can be used, though the differences are quite small.

**Table 6.16-20: VSL for EU-27**

| VSL original (OECD report 2011) million US$2005 | VSL adjusted million Euro2013 | | |
|---|---|---|---|
| income elasticity over space | 0.4 | 0.8 | 1 |
| income elasticity over time | 1 | 1 | 1 |
| 1.80 | 1.52 | 1.47 | 0.92 |
| 3.60 | 3.04 | 2.94 | 1.84 |
| 5.40 | 4.57 | 4.41 | 2.76 |

Note: US$2005
Source: OECD (2011) adjustment.

**Table 6.16-21: VOLY for EU-27**

| VOLY original (Spadaro 2004) (euro2013) 90,000 | VOLY adjusted (Euro2013) |
|---|---|
| income elasticity over space | |
| 0.4 | 83,946 |
| 0.8 | 78,299 |
| 1.0 | 75,620 |

Note: EUR2013
Source: De Ayala, Spadaro (2014) adjustment.

**Table 6.16-22: VOLY for UK**

| VOLY original (Chilton et al 2004) (£2004) 7,280 | VOLY adjusted (Euro2013) income elasticity over time | | |
|---|---|---|---|
| income elasticity over space | 0.4 | 0.8 | 1 |
| 0.4 | 9,002 | 8,815 | 8,722 |
| 0.8 | 7,641 | 7,482 | 7,404 |
| 1.0 | 7,040 | 6,893 | 6,821 |

Note: £2004
Source: Chilton et al (2004) adjustment.

The final values used are summarised in the table below (Table 6.16-23).

**Table 6.16-23: Economic values used for the monetization of the health benefits.**

| Monetary value | Health indicator | Source |
|---|---|---|
| VSL = 2.94 Million Euro2013 | All deaths, and premature deaths | OECD, 2011 |
| VOLY = 7,404 Euro2013 | Displaced years life lost | Chilton et al, 2004 |
| VOLY = 78,299 Euro2013 | Premature years life lost | Spadaro and de Ayala, 2014 |

*Projections of benefits to 2100*

Table 6.16-24 and Table 6.16-25 show the discounted economic benefits of the HHWWS in the four scenarios for RCP4.5 and 8.5 over the period 2020-2100. We carried out the analysis for all the scenarios of economic valuation, but we show the results only in one case: VOLY for premature mortality (de Ayala and Spadaro, 2014) and VOLY (Chilton et al 2004) for displaced mortality, as this represents the lower bound estimate for the monetary benefits. In all other cases, the CBR would be higher as the monetary benefits are higher.

Table 6.16-24: Discounted economic benefits of the HHWWS, scenario RCP4.5 (SSP2)

| S1 - no acclimatisation, Tcrit constant=34 | d=0 | d=1 | d=2 | d=3 | d=5 |
|---|---|---|---|---|---|
| HHWSeff=low | 3,170 | 2,057 | 1,403 | 1,003 | 583 |
| HHWSeff=avg | 3,602 | 2,337 | 1,594 | 1,140 | 662 |
| HHWSeff=high | 4,082 | 2,649 | 1,806 | 1,292 | 750 |
| **S1a - acclimatisation, Tcrit increasing** | **d=0** | **d=1** | **d=2** | **d=3** | **d=5** |
| HHWSeff=low | 3,134 | 2,038 | 1,393 | 998 | 580 |
| HHWSeff=avg | 3,561 | 2,316 | 1,583 | 1,134 | 659 |
| HHWSeff=high | 4,036 | 2,625 | 1,794 | 1,285 | 747 |

Sources: VOLY estimates for premature mortality figures based on de Ayala and Spadaro (2014) and displaced mortality figures based on Chilton et al (2004).

Table 6.16-25: Discounted economic benefits of the HHWWS, scenario RCP8.5 (SSP5)

| S2 - no acclimatisation, Tcrit constant=34 | d=0 | d=1 | d=2 | d=3 | d=5 |
|---|---|---|---|---|---|
| HHWSeff=low | 5,251 | 3,170 | 2,011 | 1,344 | 698 |
| HHWSeff=avg | 5,968 | 3,603 | 2,285 | 1,527 | 794 |
| HHWSeff=high | 6,763 | 4,083 | 2,590 | 1,730 | 899 |
| **S2a - acclimatisation, Tcrit increasing** | **d=0** | **d=1** | **d=2** | **d=3** | **d=5** |
| HHWSeff=low | 5,420 | 3,221 | 2,015 | 1,331 | 682 |
| HHWSeff=avg | 6,159 | 3,660 | 2,290 | 1,512 | 776 |
| HHWSeff=high | 6,980 | 4,148 | 2,595 | 1,714 | 879 |

Sources: VOLY estimates for premature mortality figures based on de Ayala and Spadaro (2014) and displaced mortality figures based on Chilton et al (2004).

**What is the evaluation time frame?**

What is the lifespan of the measure with the longest lifetime?

The evaluation time frame is 80 years, 2020-2100. We consider that green roof has an initial cost and a maintenance cost. The maintenance cost account for a renewing of the roof every 30 years in addition to the annual maintenance.

The costs of the HHWS are fixed costs of maintaining the system and variable costs per days. The latter are multiplied by the number of days in which the system is expected to be launched (when the maximum daily temperature is higher than the stated critical threshold Tcrit).

**Which discount rate should be applied?**

Which discount rate is recommended by national guidelines for climate change adaptation measures (or public investments)?

We use a linear discounting over time. We give results for a 0%, 1%, 2%, 3% and 5% discount rate.

**How to deal with data uncertainty?**

Uncertainties are considered in the case study both in the scaling parameter setting and in the analysis of the results. In the first place a Monte Carlo simulation is performed on socioeconomic and climatic data. The cost-benefit analysis includes a sensitivity analysis.

Figure 6.16-14 shows the methodology used to analyse uncertainty in the case study.

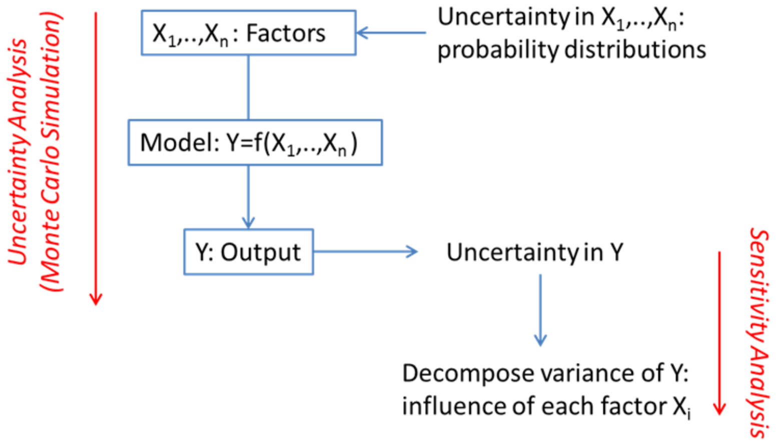



**Figure 6.16-14: Approach for dealing with uncertainty**

**Step 5 – Evaluation and Prioritization**

**What is the ranking order of alternative adaptation options (measures, bundles of measures or pathways)?**

**Benefit-Cost ratio for green roof in Madrid**

Table 6.16-26 and Table 6.16-27 show the benefit-cost ratios (BCR) under the socio-climatic scenarios: SSP2/Rcp4.5 and SSP5/Rcp8.5. Given non linearities in the estimation, results are presented for the different scenarios of green roof coverage. The BCR are estimated for the different discount rates. Finally, to illustrate the uncertainty in the BCR we combine low, medium and high estimates (9 combinations in total).

**Table 6.16-26: The benefit cost ratios for SSP2 and Rcp4.5**

| | | Low/Low | Low/ Medium | Low/High | Medium/Low | Medium/Medium | Medium/High | High/Low | High/Medium | High/High |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **Green roof 5%** | | | | |
| Discount arte | **0%** | 0.67 | 0.27 | 0.15 | **1.68** | 0.67 | 0.38 | **3.52** | **1.41** | 0.80 |
| | **1%** | 0.58 | 0.22 | 0.12 | **1.40** | 0.53 | 0.30 | **2.88** | **1.09** | 0.62 |
| | **2%** | 0.48 | 0.17 | 0.10 | **1.13** | 0.41 | 0.23 | **2.29** | 0.82 | 0.47 |
| | **3%** | 0.38 | 0.13 | 0.08 | 0.90 | 0.31 | 0.18 | **1.79** | 0.62 | 0.35 |
| | **5%** | 0.23 | 0.08 | 0.04 | 0.57 | 0.19 | 0.11 | **1.11** | 0.37 | 0.21 |
| | | | | | | **Green roof 20%** | | | | |
| Discount rate | **0%** | 0.60 | 0.24 | 0.14 | **1.61** | 0.64 | 0.36 | **3.20** | **1.28** | 0.73 |
| | **1%** | 0.52 | 0.20 | 0.11 | **1.34** | 0.51 | 0.29 | **2.65** | **1.00** | 0.57 |
| | **2%** | 0.43 | 0.15 | 0.09 | **1.09** | 0.39 | 0.22 | **2.13** | 0.77 | 0.44 |
| | **3%** | 0.34 | 0.12 | 0.07 | 0.87 | 0.30 | 0.17 | **1.69** | 0.59 | 0.34 |
| | **5%** | 0.22 | 0.07 | 0.04 | 0.55 | 0.18 | 0.11 | **1.09** | 0.36 | 0.21 |
| | | | | | | **Green roof 50%** | | | | |
| Discount rate | **0%** | 0.60 | 0.24 | 0.14 | **1.56** | 0.62 | 0.35 | **3.15** | **1.26** | 0.71 |
| | **1%** | 0.52 | 0.20 | 0.11 | **1.30** | 0.49 | 0.28 | **2.61** | 0.99 | 0.56 |
| | **2%** | 0.43 | 0.16 | 0.09 | **1.05** | 0.38 | 0.22 | **2.10** | 0.76 | 0.43 |
| | **3%** | 0.35 | 0.12 | 0.07 | 0.84 | 0.29 | 0.17 | **1.67** | 0.58 | 0.33 |
| | **5%** | 0.22 | 0.07 | 0.04 | 0.53 | 0.18 | 0.10 | **1.07** | 0.35 | 0.20 |
| | | | | | | **Green roof 100%** | | | | |
| Discount rate | **0%** | 0.60 | 0.24 | 0.14 | **1.53** | 0.61 | 0.35 | **3.01** | **1.20** | 0.68 |
| | **1%** | 0.52 | 0.20 | 0.11 | **1.28** | 0.48 | 0.27 | **2.48** | 0.94 | 0.53 |
| | **2%** | 0.43 | 0.15 | 0.09 | **1.04** | 0.37 | 0.21 | **2.00** | 0.72 | 0.41 |
| | **3%** | 0.35 | 0.12 | 0.07 | 0.83 | 0.29 | 0.16 | **1.58** | 0.55 | 0.31 |
| | **5%** | 0.22 | 0.07 | 0.04 | 0.52 | 0.17 | 0.10 | **1.01** | 0.34 | 0.19 |

Notes: Low/Low means the benefit-cost ratio has been estimated with the low estimates of the benefits and the low estimates of the cost. Low/Medium means low benefits and low costs. A ratio < 1 means that the costs are higher than the benefits and would lead to the no-implementation of the policy.

**Table 6.16-27: The benefit cost ratios for SSP5 and Rcp8.5**

| | | Low/Low | Low/ Medium | Low/High | Medium/Low | Medium/Medium | Medium/High | High/Low | High/Medium | High/High |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | **Green roof 5%** | | | | |
| **Discount arte** | **0%** | 0.67 | 0.27 | 0.15 | **1.68** | 0.67 | 0.38 | **3.53** | **1.42** | 0.80 |
| | **1%** | 0.58 | 0.22 | 0.12 | **1.41** | 0.53 | 0.30 | **2.89** | **1.09** | 0.62 |
| | **2%** | 0.48 | 0.17 | 0.10 | **1.14** | 0.41 | 0.23 | **2.30** | 0.83 | 0.47 |
| | **3%** | 0.38 | 0.13 | 0.08 | 0.90 | 0.31 | 0.18 | **1.80** | 0.63 | 0.36 |
| | **5%** | 0.24 | 0.08 | 0.04 | 0.57 | 0.19 | 0.11 | **1.12** | 0.37 | 0.21 |
| | | | | | | **Green roof 20%** | | | | |
| **Discount rate** | **0%** | 0.60 | 0.24 | 0.14 | **1.61** | 0.65 | 0.37 | **3.22** | **1.29** | 0.73 |
| | **1%** | 0.52 | 0.20 | 0.11 | **1.35** | 0.51 | 0.29 | **2.66** | **1.01** | 0.57 |
| | **2%** | 0.43 | 0.16 | 0.09 | **1.10** | 0.40 | 0.22 | **2.14** | 0.77 | 0.44 |
| | **3%** | 0.35 | 0.12 | 0.07 | 0.87 | 0.30 | 0.17 | **1.70** | 0.59 | 0.34 |
| | **5%** | 0.22 | 0.07 | 0.04 | 0.56 | 0.19 | 0.11 | **1.09** | 0.36 | 0.21 |
| | | | | | | **Green roof 50%** | | | | |
| **Discount rate** | **0%** | 0.61 | 0.24 | 0.14 | **1.56** | 0.63 | 0.35 | **3.16** | **1.27** | 0.72 |
| | **1%** | 0.52 | 0.20 | 0.11 | **1.31** | 0.49 | 0.28 | **2.62** | 0.99 | 0.56 |
| | **2%** | 0.43 | 0.16 | 0.09 | **1.06** | 0.38 | 0.22 | **2.11** | 0.76 | 0.43 |
| | **3%** | 0.35 | 0.12 | 0.07 | 0.84 | 0.29 | 0.17 | **1.68** | 0.58 | 0.33 |
| | **5%** | 0.22 | 0.07 | 0.04 | 0.54 | 0.18 | 0.10 | **1.07** | 0.36 | 0.20 |
| | | | | | | **Green roof 100%** | | | | |
| **Discount rate** | **0%** | 0.60 | 0.24 | 0.14 | **1.53** | 0.61 | 0.35 | **3.02** | **1.21** | 0.68 |
| | **1%** | 0.52 | 0.20 | 0.11 | **1.28** | 0.49 | 0.27 | **2.50** | 0.94 | 0.53 |
| | **2%** | 0.43 | 0.16 | 0.09 | **1.04** | 0.38 | 0.21 | **2.01** | 0.72 | 0.41 |
| | **3%** | 0.35 | 0.12 | 0.07 | 0.83 | 0.29 | 0.16 | **1.59** | 0.55 | 0.32 |
| | **5%** | 0.22 | 0.07 | 0.04 | 0.53 | 0.18 | 0.10 | **1.01** | 0.34 | 0.19 |

Notes: Low/Low means the benefit-cost ratio has been estimated with the low estimates of the benefits and the low estimates of the cost. Low/Medium means low benefits and low costs. A ratio < 1 means that the costs are higher than the benefits and would led to the no-implementation of the policy.

First the BC ratios vary with the green roof scenarios and with the discount rate. The UHI reduction assumption makes that the benefits vary non-linearly with the temperature. The health, energy and carbon benefits are subject to thresholds temperature which makes the number of days where the benefits is observed different from one green roof scenario to another.

Within each socio-climatic scenario, the variability is high between the different combinations of benefits and costs: from BC ratios lower than 1, which would reject the green roof implementation to BC ratios larger than one. The BC ratios larger than one correspond to case where the estimated costs are low or medium and the benefits are medium to high.

Finally, we do not observe significant difference in the BC ratio between the two socio-economic scenarios: both in the magnitude of the ratio and in the case where the ratio is smaller or larger than one.

**Benefit-Cost ratio for HHWS in Madrid**

As for the HWWS, the following tables report the benefit-cost ratio for the period 2020-2100 for RCP4.5 and 8.5 for the following hypothesis:

1. High, average and low effectiveness of the system.
2. High, average and low cost of the HWWS.

As for the monetary benefits, the lower bound values have been used (VOLY for premature and displaced mortality). Results show always a positive ratio with high expected health benefits if compared with the costs, indicating that the HHWWS is a low regret measure. The ratio increases when the effectiveness of the system increases, while it decreases when the cost of the system increases.

**Table 6.16-28: Benefit-cost ratio of HHWWS for RCP4.5 and SSP2, period 2020-2100.**

| **S1 - no acclimatisation, Tcrit constant=34** | | **d=0** | **d=1** | **d=2** | **d=3** | **d=5** |
|---|---|---|---|---|---|---|
| HHWScost=avg | Effect=low | 356 | 345 | 333 | 320 | 297 |
| HHWScost=avg | Effect=avg | 404 | 392 | 378 | 364 | 338 |
| HHWScost=avg | Effect=high | 458 | 444 | 429 | 412 | 383 |
| HHWScost=low | Effect=avg | 1,792 | 1,736 | 1,673 | 1,609 | 1,491 |
| HHWScost=high | Effect=avg | 228 | 221 | 213 | 205 | 190 |
| **S1a - acclimatisation, Tcrit increasing** | | **d=0** | **d=1** | **d=2** | **d=3** | **d=5** |
| HHWScost=avg | Effect=low | 439 | 413 | 386 | 362 | 322 |
| HHWScost=avg | Effect=avg | 499 | 469 | 439 | 411 | 366 |
| HHWScost=avg | Effect=high | 566 | 531 | 497 | 466 | 414 |
| HHWScost=low | Effect=avg | 2,203 | 2,069 | 1,937 | 1,814 | 1,613 |
| HHWScost=high | Effect=avg | 282 | 264 | 247 | 232 | 206 |

Sources: VOLY for premature, de Ayala and Spadaro (2014) and VOLY for displaced, Chilton et al (2004)

**Table 6.16-29: Benefit-cost ratio of HHWWS for RCP8.5 and SSP5, period 2020-2100.**

| **S2 - no acclimatisation, Tcrit constant=34** | | **d=0** | **d=1** | **d=2** | **d=3** | **d=5** |
|---|---|---|---|---|---|---|
| HHWScost=avg | Effect=low | 438 | 411 | 383 | 356 | 310 |
| HHWScost=avg | Effect=avg | 497 | 467 | 436 | 405 | 352 |
| HHWScost=avg | Effect=high | 564 | 529 | 494 | 459 | 399 |
| HHWScost=low | Effect=avg | 2,212 | 2,076 | 1,934 | 1,795 | 1,560 |
| HHWScost=high | Effect=avg | 280 | 263 | 245 | 228 | 199 |
| **S2a - acclimatisation, Tcrit increasing** | | | | | | |
| HHWScost=avg | Effect=low | 723 | 637 | 556 | 486 | 382 |
| HHWScost=avg | Effect=avg | 821 | 724 | 632 | 552 | 434 |
| HHWScost=avg | Effect=high | 931 | 820 | 716 | 626 | 492 |
| HHWScost=low | Effect=avg | 3,628 | 3,194 | 2,790 | 2,437 | 1,916 |
| HHWScost=high | Effect=avg | 463 | 408 | 356 | 311 | 245 |

Sources: VOLY for premature, de Ayala and Spadaro (2014) and VOLY for displaced, Chilton et al (2004)

**What are the uncertainties associated with the performance of the different options?**

The benefit-cost ratio is derived for 5 services of green roofs and we have seen the list of services is even longer. As we add other services, we would reduce the epistemic or knowledge-based uncertainty and this would change the value of the benefit-cost ratio but will not change the ontological uncertainty inherent to the natural variability of the processes. Moreover, a literature review from the non-estimated services tends to show that knowledge gap for the estimation of these services is high.

Then the CBA is sensitive to the socio-climatic scenario: the low mitigation (SSP5 and Rcp85) and the higher mitigation scenario (SSP2 and Rcp45). It is also sensitive to the discount rate as we illustrated it: using 0%, 1%, 2%, 3% or 5% and non-linear discounting will change considerably the costs and the benefits. Then each type of services and costs are estimated with low, average and high parameters: results of the benefits costs ratio are very sensitive to this parameters' range.

Moreover, we have seen that the larger benefit is due to health services. This effect is subject to 2 sources of uncertainty: on the one hand the uncertainty in the epidemiologic relations (health-temperature relationship) and the economic valuation of mortality and on the other hand the uncertainty relative the outdoor temperature reduction obtained from green roofs from which the health service is derived. If the first source of uncertainty has can be reduced with empirical analysis of the literature, the gap reduction of the second source of uncertainty is much more difficult to address as very little experience of green roof contribution to urban heat island reduction exists. Moreover, a critical mass of green roof would be required to obtain such a UHI.

As for the HHWWS there are different sources of uncertainties in relation to the following factors:

1. Changing of Tcrit (threshold temperature), AR (attributable risk) and DMR (displaced mortality rate) can follow different potential paths of evolution over time. The change of Tcrit is analysed through a probability density function based on projections of future daily maximum temperatures under scenarios RCP4.5 and 8.5 (Monte Carlo simulations), and in the CBA carried out for the HHWWS for Madrid just one possible trajectory of evolution as been considered, to simplify the calculations: the one based on the annual mean Tcrit temperature of the random, stepwise Tcrit trajectories assumed in the Monte Carlo simulations (see Fig. 15 and 16). Also for the AR and DMR, among the potential curves of risk evolution and DMR decreasing paths (based on Monte Carlo simulations), the mean curves have been considered (Fig. 17 and 18) for simplicity.
2. Dose-response function and epidemiological limitations (Diaz et al, 2014a and 2014b).
3. Health impact assessment:
    - Displaced mortality has been assumed to be 40% but for sensitivity analysis of the impacts it would be useful to use also an upper bound (see paper of Hajat et al, 2005).
    - Estimation of the years of life lost (LYL): for displaced and premature mortality the mean loss of life over the period 2020-2100 has been used (16 days and 4.7 years per deaths respectively), though for sensitivity

analysis the health impacts are estimated using a lognormal distribution (for simplicity the latter is not considered in the calculation of the BCR).

4. Monetisation of the health benefits and values to use (VSL versus VOLY, and reference values for each of them). According to the economic value used, different BCR can be derived. We calculated the BCR for the following cases:
   - VSL for all deaths.
   - VSL only for premature deaths and no value for displaced mortality.
   - VOLY for both premature and displaced mortality.
   - Using the VSL for all deaths provides an upper bound of the benefits, VOLY for premature and displaced deaths gives a lower bound, while using VSL only for premature deaths gives a medium estimate for the economic benefits. In the case of the HHWWS for Madrid, however, the BCR is always strongly positive, so the choice of the economic unit for the health valuation does not affect the final results of the BCR (>1).
5. Effectiveness of the HHWWS: the results of the model of Fouillet et al (2008) have been used as a reference of the range values for the effectiveness of the HHWWS in Madrid, for lack of specific data for the system of Madrid.
6. The variable costs of the HHWWS are derived and adapted from a study done by Ebi (2004), while only the fixed costs are specific to Madrid system.

The CBR is sensitive to the climate change scenario (RCP 4.5 versus RCP8.5) and to the discount rate as we illustrated: 0%, 1%, 2%, 3% or 5%.

## What are the main lessons learnt from your case study?

**Transferable results?**

The results give an idea of the economy of adaptation in Mediterranean cities, which have a specific performance under climate change conditions. The sensitivity of results to climate data makes final results geographically depends. Results could be transferred to similar climate and cities. All the parameters of this model, expect those of water retention services are parameters that were estimated in the literature for Madrid or for Spain.

For the HHWWS, the methodological framework for the estimation of the health impacts, evolution of Tcrit, AR and DMR, as well as the CBA framework could be transferred to other geographical contexts, while the specific values estimated for Tcrit and attributable risk from the epidemiological study cannot be transferred as they specifically apply to Madrid. Each city is characterised by its own Tcrit (at which daily mortality starts to increase significantly), and has a specific attributable risk for mortality.

**Lessons learnt with regard to the process of economic evaluation?**

Estimating the benefits of green roof in physical terms (i.e. non-monetary) is a very challenging exercise given the little (but increasing) knowledge on green roofs at meso-scales. The most uncertain one is the urban heat island (UHI) effect reduction. If UHI is well documented for Madrid at spatial scale, the contribution of green roof in reducing UHI is mostly unknown in Madrid, in a single estimation isolated of other adaptation measures like air conditioning reduction (Salamanca et al 2012). The literature review of UHI reduction informs that the higher temperature reduction can be expected when air conditioning is turn off. More generally UHI would be reduced ore effectively by tackling the causes of UHI, e.g. air conditioning, than by using engineering solutions like green roofs. We present UHI reduction scenario based on the literature but the uncertainty is large.

The monetary valuation of the services presents the usual challenges when services are intangible and when limited access to data makes the use of a proxy necessary.

Climate change gives a particular interest to the study as it needs to relate services with climatic phenomenon: rainfall and temperature. The model developed estimates 5 urban services based on temperature threshold and rainfall threshold. For energy consumption reduction, the model uses of the number of days in the future where the maximum temperature is above a given threshold (28ºC). But it is also well know that energy consumption is not linear with outdoor temperature: then cooling a house would cost more when outdoor temperatures increases. Accounting for this effect would require a model where energy savings from cooling are related to outdoor temperature in addition to the indoor targeted temperature. For water retention services, the rainfall pattern also influence the capacity of retention of the roof. The climatic data do not allow such estimation. Considering this daily pattern would maybe change the type of valuation of the services: in addition to a reduction of water treatment, the retention of water on the roof would reduce the flooding of the street during storm events.

Then the choice of extensive green roofs (contrary to intensive roofs) results from their better adaptation to dry climate with water stresses and drought in summer but extensive roofs generate also less services than intensive ones. Accounting for intensive roof would require to account for water needs and water supply in dry climates.

As for the HHWWS, the monetary valuation of the health impacts refers to the well-known measures of VSL and VOLY, which have been extensively debated in the literature. Many economists question the use of these values in CBA on ethical grounds given the uncertainties and biases intrinsic to the valuation methods applied, though many recommendations have been developed to correct for existing limitations. In any case, as stated in OECD (2011), "even if mortality risks are not valued explicitly, they will still be valued implicitly through the decisions that are made" in policy contexts. Therefore, it is preferred to use explicit values (providing clear and transparent information on the non-market methods or benefit transfer techniques) so that to make more consistent policy decisions.

OECD guidelines (2011) recommend to use VSL for valuing mortality risk changes, while VOLY should be used only if based on primary surveys valuing VOLY directly (for which only few studies are available in the literature). In our case study we use both indicators to provide a range of economic benefits, and because we think that VOLY might be more appropriate than VSL to value displaced mortality specifically. Actually, in the case of Madrid, the years of life lost (LYL) for displaced mortality are very low (16 days), meaning that these people would have died regardless the heatwaves episode.

The following values have been chosen:

- VSL proposed by OECD (2011) for EU-27, based on literature review and the most comprehensive meta-analysis of stated preference studies (Lindhjem et al, 2010 and 2011).
- VOLY for one month gain in life expectancy in poor health for acute mortality in a context of air pollution (Chilton et al, 2004). We think this study is the most appropriate to be applied in a context of heatwaves to value displaced deaths, for the similarities of the background (the LYL are between 1 week and 1 month in poor health for displaced mortality in Madrid) (the choice is in line with OECD guidelines according to which the use of VOLY is justified when based on primary surveys estimating the WTP for the specific change in life expectancy directly).
- VOLY adjusted for VSL/VOLY for people in normal health (de Ayala and Spadaro, 2014) for premature chronic mortality, which accounts for 4.7 years of life lost on average.

With the above values, the following scenarios are proposed:

- VSL for all deaths (which provides an upper bound estimate).
- VSL only for premature deaths (considering that the LYL for displaced mortality are very low). Attaching a VOLY estimate for displaced mortality would not change much the final results, due to the small number of LYL for displaced mortality and the low VOLY (based on Chilton et al, 2004)
- VOLY for premature mortality (normal health, chronic mortality) and VOLY for displaced mortality (one month gain in poor health, acute mortality)

**Important data sources**

Instituto Nacional de Estadística (National Statistics Institute), Ayuntamiento de Madrid (Madrid Municipality), Instituto Nacional de Meteorología (National Metereologic Institute) and Plan General de Madrid (Madrid Town Plan), the Construction Databases from the Technical Architects Association, Building Companies and Experts

## 6.17 Adaptation of water for rice in a coastal wetland, Doñana, Spain

Ana Iglesias, Pedro Iglesias, Luis Garrote, Alvaro Sordo, Luis Mediero, Berta Sanchez; UPM

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

**Water availability and potential policy choices**

Climate change jeopardizes the equilibrium of water resources in the Guadalquivir water district and the impacts will vary as a result of local regulation capacity. The difference between runoff and water availability is defined by the effect of storage. Reservoir regulation is one of the most important water resources management policies in water-scarcity areas and has generated significant impacts. Existing reservoirs are being subjected to intense multi-objective demands on limited resources (i.e., water supply, flood control, hydropower, navigation, fish and wild life conservation, recreation, and water quality by assimilating waste effluents.)

These scenarios of water availability) demonstrate that in water scarcity regions, water availability is likely to be one of the great future challenges. Defining future water availability under different adaptation policy options is therefore a basic step for water policy formulation.

Reductions of water runoff and increased variability, resulting from exposure to climate change, will lead to significant decreases in the water availability. This clearly demands for adaptation policy measures. Here we only consider impositions of demand restrictions since regulatory capacity is already at a maximum in the river district. This is particularly true in the case of irrigation water demand scenarios since it is reasonable to assume that, without changes in policy, land use or technology, projected irrigation demand in the basin will be higher than present irrigation demand even if farmers apply efficient management practices and adjust cropping systems to the new climate. Moreover, when policy and technology remain constant, it has been shown that agricultural water demand will increase in all scenarios in the region (Iglesias et al., 2007, Iglesias 2009). The main drivers of this irrigation demand increase are the decrease in effective rainfall and increase in potential evapotranspiration (due to higher temperature and changes of other meteorological variables).

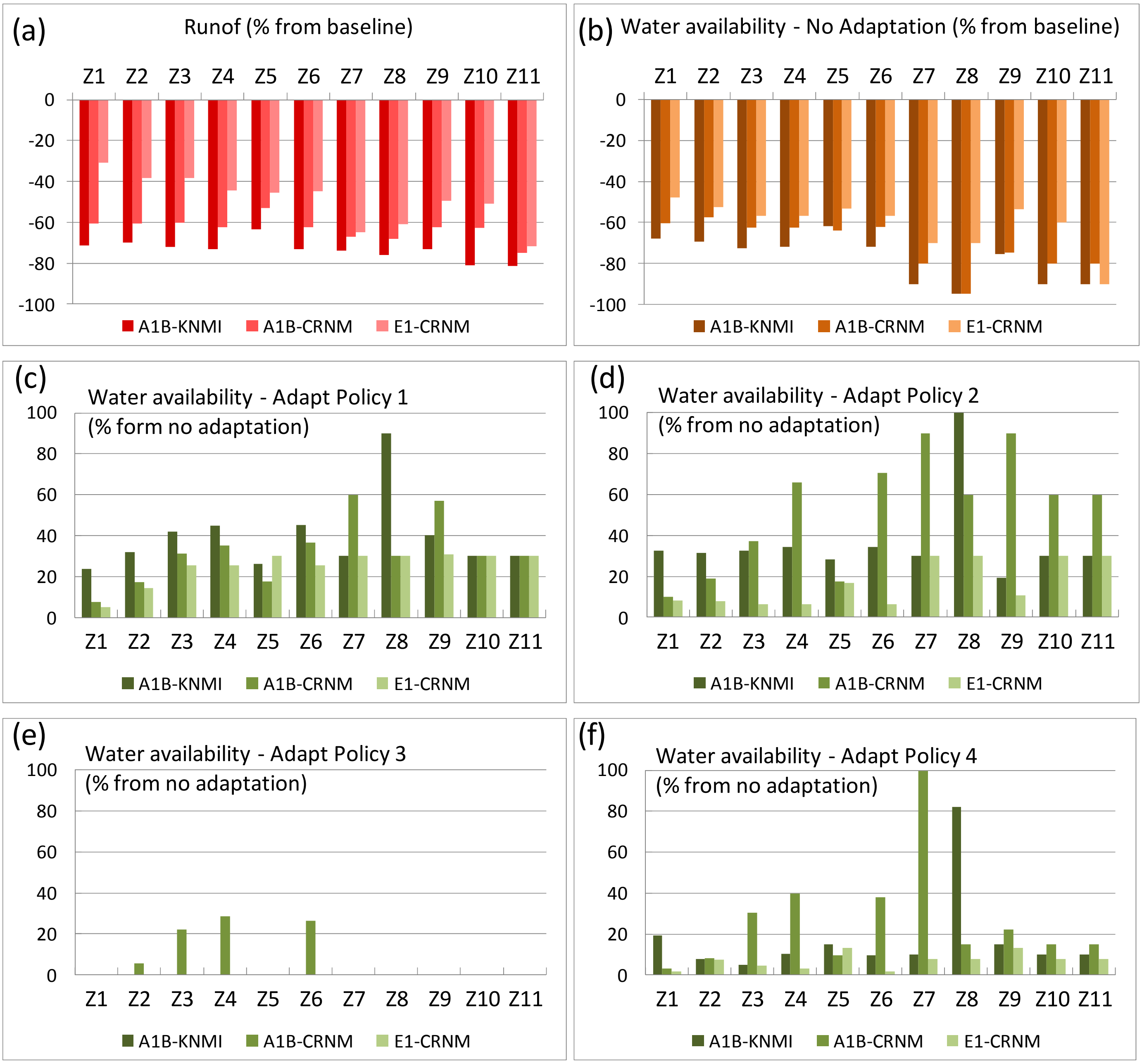



**Figure 6.17-1: Effect of climate change scenario (2070-2100) with respect to control run (1960-1990) for the RCM models forced with two emission scenarios in the Guadalquivir water district.**

Notes: (a) Per unit reduction of runoff; (b) water availability for irrigation with current policy; (c) water availability for irrigation with improved water policy in urban areas; (d) water availability for irrigation with water reduced allocation for environmental uses; (e) water availability for irrigation with hydropower reservoir water conservations; (f) water availability for irrigation with improved the overall water management of the system by water interconnections.

**What is the climate change related problem/risk you would like to reduce by adaptation?**

*Which problems already exist, what is/are the current risk/s?*

The major risks in the case study area are water scarcity, salinity problems in water and soils, and to a lesser extent increased invasive species and pests and decreased rice yields and quality. Water scarcity is perceived as the most important risk because it can easily lead to fall of productivity and rice yield reductions and in turn provoke biodiversity losses.

The foresee sea level rise projections in the coastal wetland are expected to worsen the water quality in the lower part of the Guadalquivir River Basin, the case study area, due to larger marine intrusion. An increased relative water scarcity, together with higher levels of salinity, makes rise conflicts and competition among users over the allocation of water. To a lesser extent other risks identified are the increase of invasive species and pests and decrease of rice yields and quality.

*Which assets and sectors are at risk under current climate variability?*

There are a population of nearly 213,839 inhabitants in the Doñana area, whose activities are mainly addressed to agriculture and tourism and in turn the wetland provides key ecological services such as a stepping-stone in the migration route for birds and waterfowl, a home to many endemic and threatened species, regulation of the local hydrologic cycle and provision of landscape services.

Rice farming occupies the 4,2% of the irrigated area and uses the 14,3% of the annual regulated water resources of the river basin. The semiarid conditions and the salinity of soils make difficult the cultivation of many other crops in the rice area.

*Which adaptation or protection measures are already in place?*

Technological measures to increase water efficiency at the field level were most likely to be accepted for both farmer associations and environmentalists. For instance, water recirculation and reutilization within the paddy rice or increased technical efficiency of the irrigation systems. Other technological options that have already proven benefits to the rice production and are widely implemented in the area (laser levelling and integrated production) were also fully supported by the administration.

Organizational measures related to water management were positively perceived by the farmer associations and environmentalists. Their responses reflected that there is a lack of local monitoring and information on water availability and use. The provision of accurate, accessible and useful water information at different scales is essential to deal with reductions in water availability (Wei et al. 2011).

Governance measures included options addressed to improve the coordination between institutions. The critical importance of institutional good governance has been previously established as a requirement for the regional adaptation capacity by preceding research. Increase scientific research, farmer training and technical advice were governance options perceived positively by all the groups.

*How do these risks presumably change due to climate and socio-economic change?*

Higher temperatures are expected to change water demands and have direct physical effects on the plant growth and development. Pulido-Calvo et al. (2012) found that in dry periods a mean temperature increase of 1 °C in low altitude locations of the Guadalquivir River Basin will result in a mean increase of 12 % in the irrigation demand on outflows. Rice is particularly sensitive to heat stress and may suffer serious damages during the anthesis to maximum temperatures above 37 °C and especially when it is exposed to water stress during the entire flowering stage. Although the expected mid and long-term scenarios of high temperatures are not recognize as a relevant risk by responses of farmer associations, they are already changing the rice growing calendar and introducing new varieties which are more tolerant to heat stress and longer cycle rice varieties.

*What are the main drivers, impacts and affected sectors?*

Water, Agriculture and tourism

*Which climate and socio-economic scenarios are used?*

SSP5/RCP8.5, SSP2/RCP4.5, SSP3/RCP8.5

**Which adaptation tipping points can be identified?**

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

**What are the alternative adaptation measures?**

*What are the primary and secondary objectives of adaptation?*

Policy is deeply involved in the water sector. Usually, policy development is based on an historical analysis of water demand and supply. It is therefore a challenge to develop policies that respond to an uncertain future. Science-policy integration is one of the most complex challenges that the scientific and policy making communities face since it involves knowledge sharing and ex-change among a wide range of disciplines and actors.

The case study attempts to face part of this challenge by presenting an approach that assesses how people – water policy and local actors – may influence water in the costal wetland under climate change. Together – policy and stakeholder choices – may be useful in singling out areas for moving towards adaptation and dialogue. This information may be used to implement and develop policy.

*What are potential measures to meet these objectives?*

1. Construction of a pipeline connecting the reservoir with the rice fields
2. 20% reduction of rice fields

*What is your baseline option (the "business-as-usual"-option)?*

*What is the ambition level of this baseline strategy?*

There is a fragile equilibrium in the current situation, that turn into a conflict in drought periods.

*Is current backlog of investments for adaptation measures included or excluded?*

Included

*Does it include only planned adaptation or also autonomous, non-planned adaptation?*

Includes autonomous adaptation

*Are there complementary measures? Is it appropriate to bundle these measures?*

**What are alternative adaptation pathways?**

*What is the "sell-by"-date of the measures or bundles of measures?*

*What would be alternative measures or bundles of measures at these "tipping points"?*

**Step 3 - Evaluation Criteria and Method**

**Step 3a Selection of evaluation criteria**

**Which evaluation criteria should be used?**

*What are the relevant positive and negative properties of the measures (costs and benefits) to be considered in the evaluation process (economic, ecological and social effects)?*

*Costs*

- Implementation costs
- Market value of land
- Loss of economic activity
- Conflict with other users of the water district
- Environmental looses

*Benefits:*

- Environmental benefits
- Socio-economic benefits

*What is the appropriate unit to measure each of these criteria? Is the performance of the adaptation options measured in qualitative, monetary or other quantitative terms?*

The performance of the adaptation options is measured in qualitative terms.

**Step 3b Selection of evaluation method(s)**

**What is the appropriate evaluation method?**

The interrelation of the qualitative and quantitative components of the study is a challenge. Our approach to interrelation includes three steps. The first step is the characterisation of water shortages under climate change by the WAAPA model. This diagnostic step is a quantification of the potential water availability changes in the basin and in Doñana, in particular. The broader scale is necessary, since the changes at the local level – and the potential solutions - depend on the changes in the basin. The simulations of water availability changes in all sub-basins range from −45 to −93 % of current water availability.

The second step explores the choices of stakeholders. The complete stakeholder views on adaptation measures are a consequence of their recurrent exposure to water limitations under the current climate. The range of options identified includes agronomic, water management, and governance measures. The measures related to water management are then selected to provide an quantitative estimation on their effectiveness with the WAAPA model in the third step. The approach links perceptions on the potential effect of the measure with quantification by means of a water policy model. We focus on options that presented a high degree of disagreement among the stakeholders groups. The application of the WAAPA model to these choices helped clarify the objective effect of the options. Furthermore, the WAAPA model was also used to simulate policy options that could be implemented in other sectors, e.g., urban or ecosystems, since these choices could bring a quantitative perspective to compare the local community choices.

**Step 3c Weighting of evaluation criteria**

The evaluation of climate change adaptation options is a complex process due to the stakeholders' differing needs and views, and further still the difficulties involved in quantifying the effects of the options. In the Doñana Case Study the adaptation assessments entails multiple stakeholders from different sectors as well as multiple objectives related to the use of resources and perceived benefits. One of the main strengths of MCA is that it can accommodate quantitative as well as qualitative information. Due to its flexibility, the use of MCA in decision-making processes for the purpose of adaptation has considerably increased in the last decade as it provides an alternative when only partial data are available and criteria are difficult to quantify. Nonetheless, there are some difficulties associated with MCA when assigning weights to criteria and standardizing scores, principally when there are a large number of criteria and they are very different in character. In the Doñana Case Study, the criteria and criteria weights were selected in a process of public participations. The measures are detailed in the Table above. The governance measure is the one most supported.

**What are the preferences of stakeholders regarding the different evaluation criteria?**

Different stakeholders have strong differences in their preferences regarding evaluation criteria:

- Rice farmers prioritize economic looses.
- Environmentalists prioritize ecologic looses.
- The Administration does not have a very clear preference.

**Table 6.17-1: Summary stakeholders' preferences**

| Risk derived from changes in the climate / Degree of social concern | Local adaptation option | Current implementation level[1] | Acceptability to farmer associations | Acceptability to environmentalists | Support from the administration |
|---|---|---|---|---|---|
| | **I. Technological measures to face the risk** | | | | |
| Increased water scarcity /High | Water recirculation and reutilization within the paddy rice | M | | | |
| | Increase the technical efficiency of the irrigation systems | L | | | |
| | Installation of flow meters | L | | | |
| | Laser levelling | H | | | |
| | Additional water infrastructure | n.a. | | | |
| Increased water salinity /High | Water releases from upstream reservoirs | M | | | |
| | New pipeline to bring in the water directly upstream from the salt water intrusion | n.a. | | | |
| Increased soil salinity /High | Flooding irrigation systems to wash soils | H | | | |
| | Organic production (good farming practices) | L | | | |
| Increased invasive species and pests /Medium | Integrated production (inputs use efficiency) | H | | | |
| Decreased rice yield and quality /Low | New longer cycle rice varieties | L | | | |
| | New rice varieties adapted to water and heat stress | L | | | |
| | **II. Organizational measures to face the risk** | | | | |
| All risks /High | Reduction of the available cultivated surface | L | | | |
| | Crop diversification and diversification to others activities (e.g. aquaculture, agro-tourism) | L | | | |
| | Anticipating local and regional water shortages | L | | | |
| | Increase monitoring and information on water use and availability at local level | L | | | |
| | Setting of irrigation turns | M | | | |
| | **III. Governance measures to face the risk** | | | | |
| All risks /High | Actions at the basin level leading flexible adaptation strategies to climate change | L | | | |
| | Improve transparency and public participation to encourage agro-environmental awareness | L | | | |
| | Increase scientific research, field studies, | M | | | |

**Step 4 - Data collection**

**What are the costs and what are the benefits of the alternative adaptation options?**

*What potential data sources are available, including damage & impact assessment methods or existing CBA studies on adaptation measures?*

- Ministry of Health,
- Water Quality Department
- River Basin Authority,
- CEDEX (Centre for Hydrographical Studies).

**What is the evaluation time frame?**

*What is the lifespan of the measure with the longest lifetime?*

The evaluation time frame is 90 years, 2010-2100.

**Which discount rate should be applied?**

*Which discount rate is recommended by national guidelines for climate change adaptation measures (or public investments)?*

We give results for a 0%, 1%, 2%, 3% and 5% discount rate.

*Is it a linear discount rate or any other type (i.e. declining, hyperbolic, etc.)*

We use a linear discounting over time.

**How to deal with data uncertainty?**

**Step 5 – Evaluation and Prioritization**

**What is the ranking order of alternative adaptation options (measures, bundles of measures or pathways)?**

The Adaptation Policy 1 addressed to improve water urban use could reach major improvements of water availability for irrigation and in turn avoid reduced water for environmental use by adaptation policy 2.

The use of additional water infrastructure for irrigation (e.g., from hydropower reservoirs) was performed by the adaptation policy 3. The simulations showed that the effect for improving water availability of policy 3 was not significant.

Adaptation options to improve the water managements by interconnections (a new pipeline connecting upstream water bodies to the rice fields, additional releases from upstream reservoirs or transfer of water) were endorsed into adaptation policy 4. The adoption of policy 4 was specially controversy between stakeholders in their acceptance, however the simulations clearly showed improvement of less than 20 % except in a few sub-basins and scenarios.

## 6.18 Rotterdam

Femke Schasfoort, Mark Zandvoort, Deltares

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

**What is the climate change related problem/risk you would like to reduce by adaptation?**

Climate change will higher the risk of flooding due to sea level rise, increasing number of rainy spells and more severe rainfall. Additionally, a flood would have a greater impact today than it would have had 50 years ago, due to the growth of the population and urbanization of the most flood prone areas of the Netherlands. The Rotterdam area is a densely populated part of Holland (1.6 m inhabitants) with extensive economic activity. In this area, the consequences of a flood will be enormous.

The Netherlands is protected by 17.500 km of dikes, which is a grey adaptation measure. Additionally, in the Rotterdam area there are several storm surge barriers, such as the Maeslant barrier. These barriers close in cases of high water levels to protect the hinterland. As part of the Room for the River program that started as a reaction of the floods of 1993 and 1995, the Netherlands planned 32 room for the river measures. The goal of this program was to accommodate a discharge volume of 16.000 m3/s in the branches of the Rhine by 2015. The Rotterdam area implemented one of these room for the river measures, a flood plain excavation (Schasfoort et al, 2013).

Currently, not all the dikes are high enough to meet the current flood protection standards. In 2050 30% of the dikes and in 2100 50% of the dikes will not meet the current flood protection standards, due to climate change and land subsidence, which is a lot more than in the current situation. The current flood protection standards are based on a 50 year old optimization of costs and benefits (damage), which are legislated in 1996. These standards are expressed as the average exceeding frequency per year, which is an expression of the hydraulic load that a water defence must be able to withstand. For example, for the western part of the Netherlands this exceeding frequency is 1 time in the 10.000 years (Van der Most et al, 2010)

The increase in population, higher economic value behind the dikes and the effect of climate change led to the decision to update the flood protection standards. Currently, the Dutch government established the new flood protection standards, which are based on a risk assessment. In 2050 all the dikes have to meet this new standards. At that time, the dikes have to be adjusted to the then prevailing climatic situation as well. See Figure 6.18-1 and Figure 6.18-2 for both the current standards and new standards (I&M 2014).

The Dutch meteorological institute developed four different climate change scenarios for the Netherlands. These scenarios are based on a multimodel ensemble approach using GCM results of the Climate Model Diagnosis and Intercomparison group and JSC/CLIVAR Working Group on Coupled Modelling. These GCM simulations are used as boundary condition for high resolution Regional Climate models. Regional Climate Models generate information on mesoscale effects and small-scale temporal and spatial variability of meteorological variables. The Dutch meteorological institute used the KNMI Regional Climate model RACMO2 and results of the European PRUDENCE project (KNMI, 2006).

The climate change scenarios were the starting point in the development of the delta scenarios. The deltascenario add scenarios of high socio-economic growth and low socio-economic growth. The combination of climate scenarios and socio-economic scenarios results in four different scenarios. In this study we use the two most extreme ones, the steam and rest scenario. The steam scenario is comparable with RCP8.5 and SSP5 and the rest scenario with RCP4.5 and SSP3.

**Sectors under risk**

The following sectors have the highest potential damages due to floodings (DPRD 2012):

Areas inside the dike: The residential sector, mainly the areas South of Holland – New Waterway, Alblasserwaard and Vijfheerenland and Lopiker- and Krimpenerwaard have a potential high number of fatalities and high economic damages.

Areas outside the dike: Low lying nature areas and agricultural sector, current urban and residential sectors (historical city center of Dordrecht, Northern island of Rotterdam, Neighbourhood Feyenoord and the port). Expected damage will be on household content and interiors as well as failure of business processes and environmental damage.

The shipping sector will be affected by more frequently closing of the Measlantkering, due to higher water levels. Consequently, the hinterland will be less accessible.

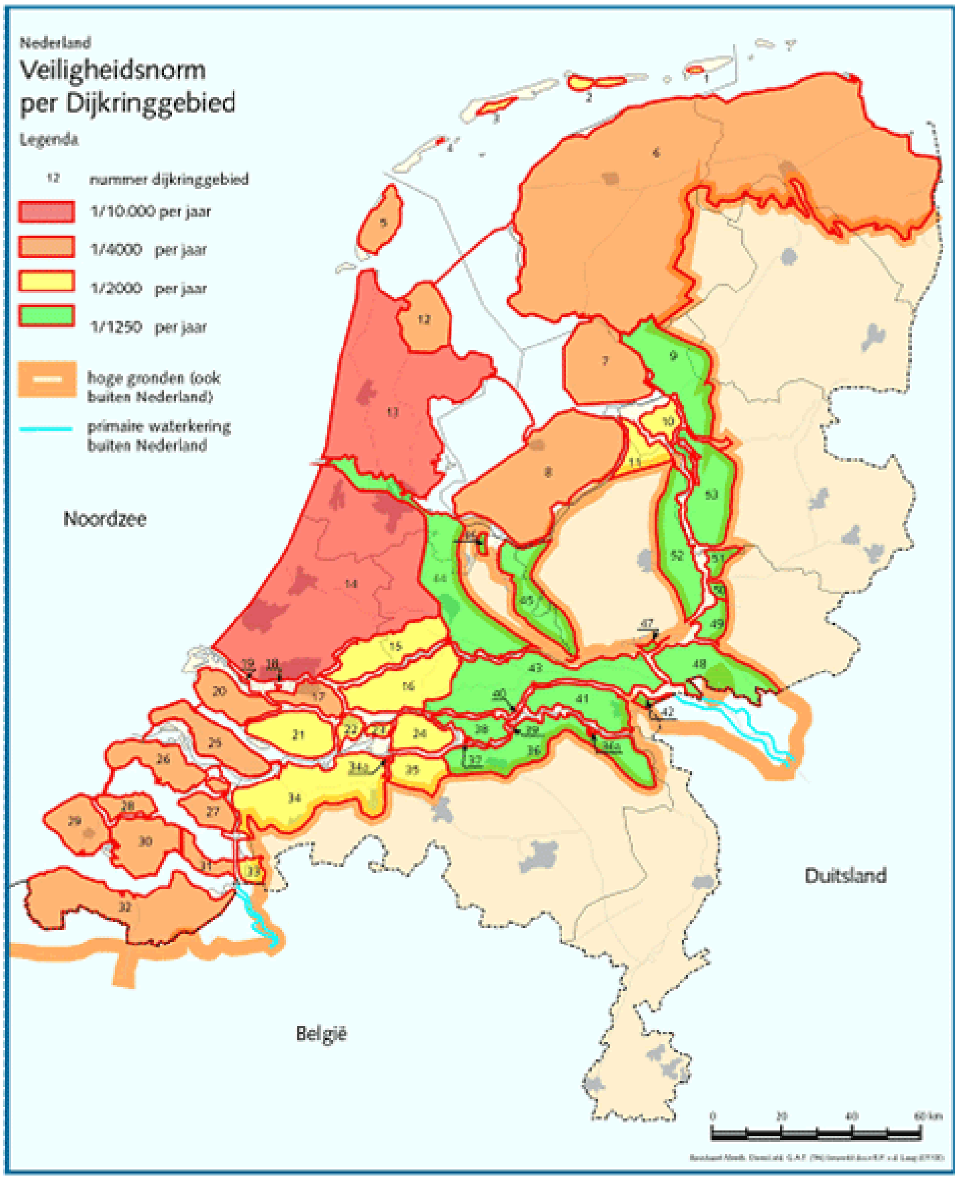



**Figure 6.18-1: Current flood protections standards**
Source: DPV 2014

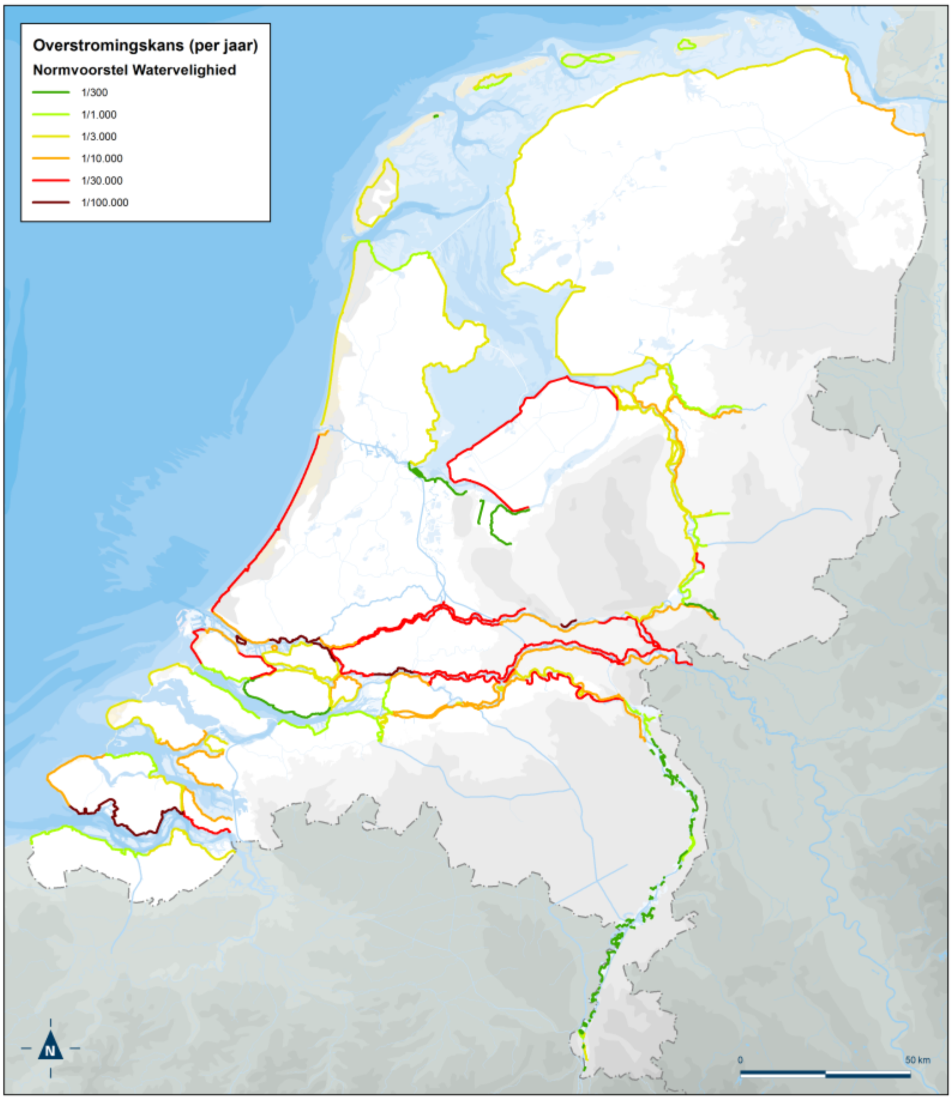



**Figure 6.18-2: Proposed flood protections standards.**
Source: DPV 2014

**Which adaptation tipping points can be identified?**

The tipping point for flood safety depends mainly on the Dutch flood protection standards. Currently, the flood safety standards are not met on all locations in the Rotterdam area, while the Dutch law subscribes that all the dikes have to meet the flood protection standards. Does this mean that the first dike stretch that will not meet the flood protection standards will cause a tipping point? However, the high water protection program will take action to higher dikes on vulnerable locations. Since, this is already embedded within current policy, it has not the characteristics of an adaption tipping point. Sea level rise and higher peak river discharges cause increasing flood risks and call for further dike improvement in complex areas (current policy) or alternative flood risk reducing measures. For example, sea level rise of 85 cm may cause a 60 to 70 cm rise in river water levels at the height of Rotterdam. The actual strength of a dike is compared with the natural variation of the hydraulic load under different scenarios. In case a dike is not strong enough it will be included in the 'high water protection programme'. However, there is a long lead time before an actual measure is taken. Figure 6.18-3 and Figure 6.18-4 give an example of already made projections of the shortage in dike height in 2050 and 2100 due to climate change for the 'steam' scenario. In 2100 in a rest scenario a similar shortage of dike height will be reached as in a 2050 steam scenario (DPRD 2012). The new flood protection standards add some complexity. In 2050 all the dikes have to meet the new standards, which mean that tipping points will change after 2050.

A dike is programmed for improvement in the national Flood Risk Management programme, whenever a dike does not meet the targets. Consequently, if a tipping point will be reached, the Flood Risk Management programme will intervene (DPRD 2014). Until 2100 the magnitude of change will not be severe enough that the current management strategy can no longer meet its objectives (Kwadijk et al 2010). Therefore, this cannot be seen as proper tipping points.

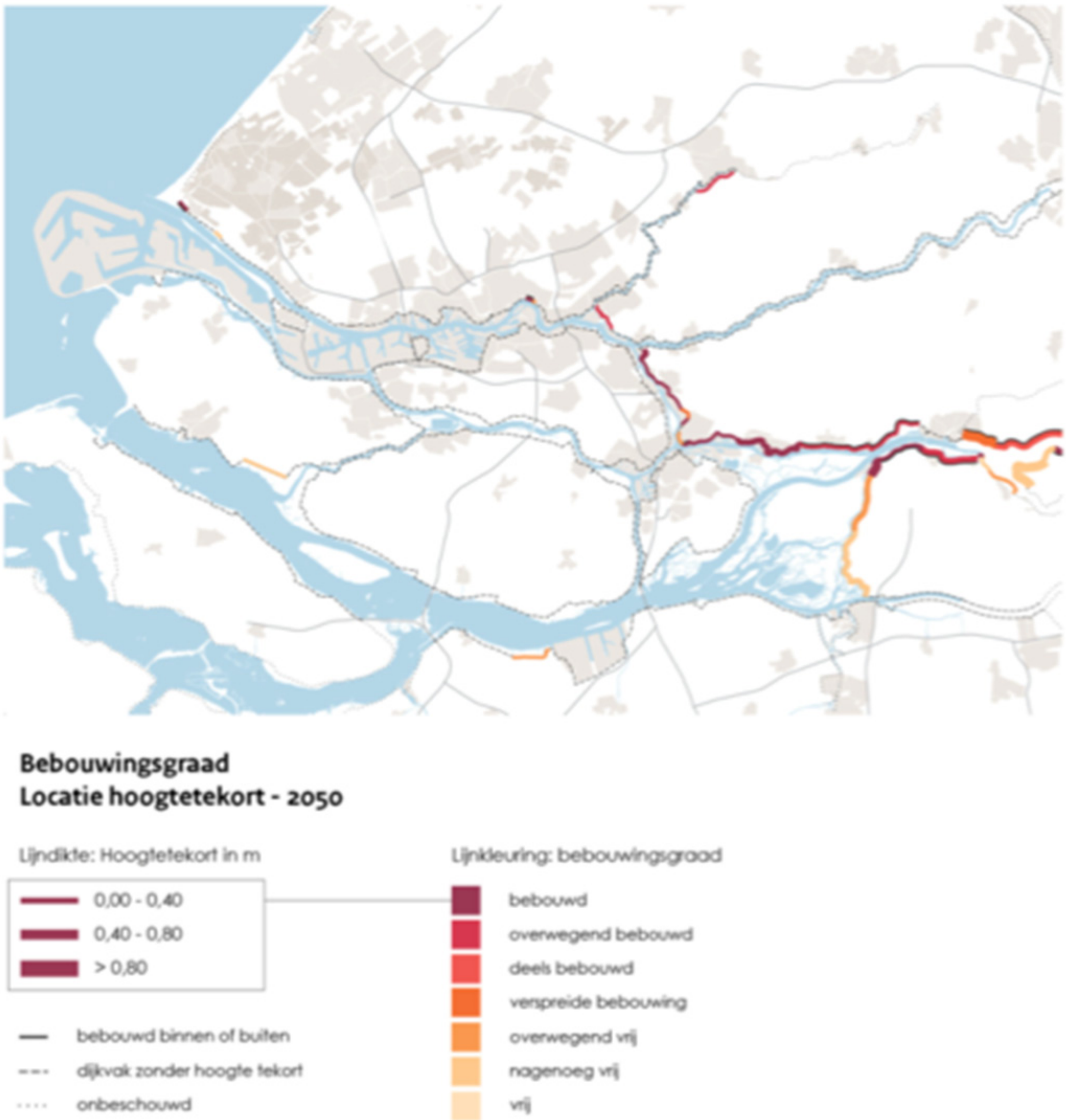



**Figure 6.18-3: Dike height shortage in 2050**
Source: DPRD (2012)

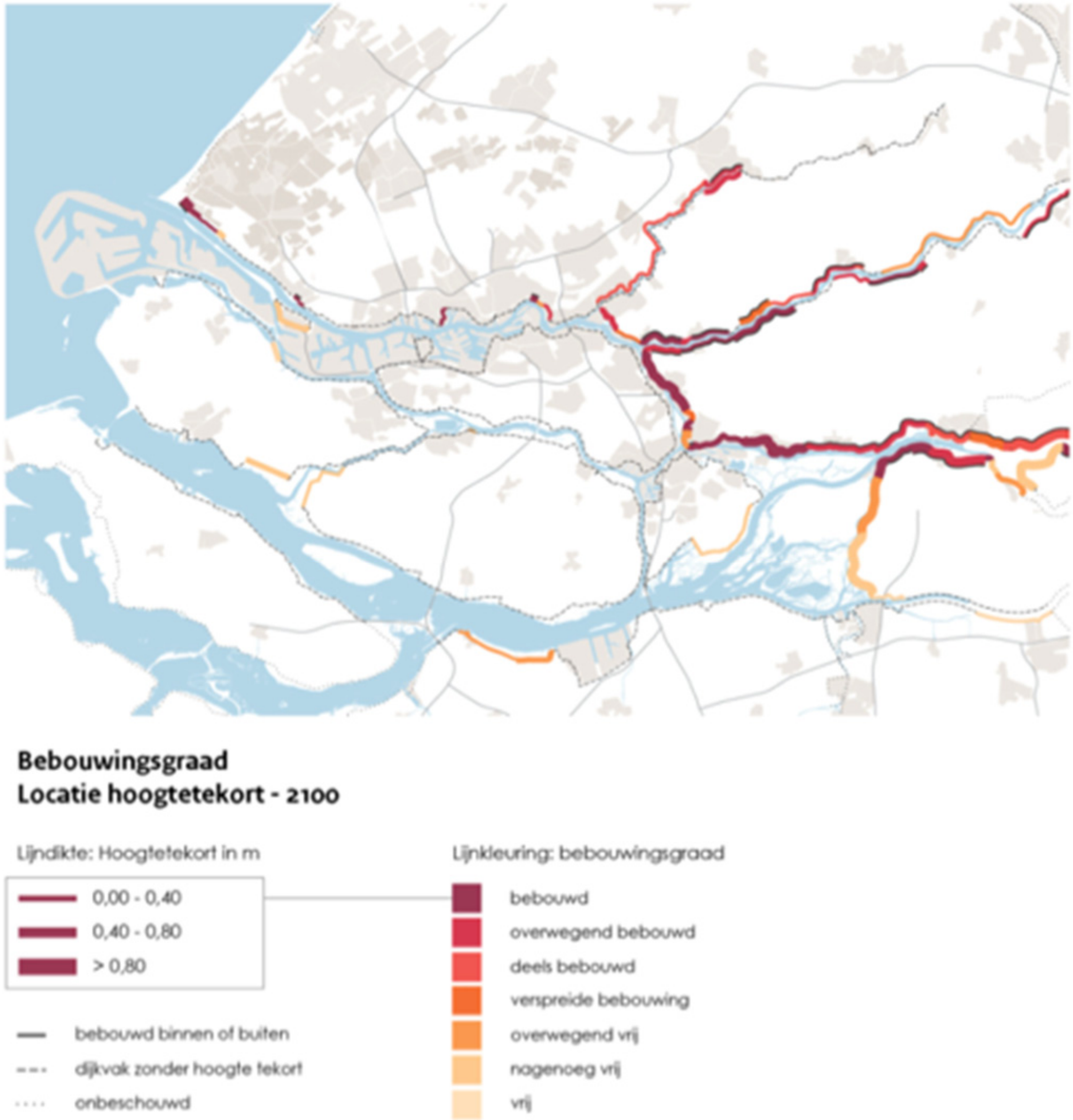



**Figure 6.18-4: Dike height shortage in 2100**
Source: DPRD (2012)

Although we see in general no tipping points due to the flood protection standards, there is one exception. The Maeslant Barrier protects the Rotterdam port and tidal river area against flooding. The barrier need to meet a safety level with a probability of occurrence between 1/10,000 and 1/ 4,000 annually. The barrier need to clos approximately every 10 years to meet this safety level. The effects of climate change imply that the barrier will close more often. Since closing of the barrier hinders navigation, the Rotterdam Port Authority accepts a maximum closing frequency of the Maeslant barrier of once per year. This will approximately reached with a sea level rise of 85 cm. This will be an adaptation tipping point (Kwadijk et al, 2010). Another adaptation tipping point is the maximum sea water level rise the barrier has been designed for, which is 50 cm. Depending on the climate scenario the barrier have to be replaced in 2070 or 2120 (Jeuken et al, 2013).

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

**What are the alternative adaptation measures?**

The main aim of the adaptation measures is to keep the country safe from flooding. This can be done either through reducing the probability of a flood or by reducing the consequences of a flood. The following type of measures reduces the probability (DPRD 2012):

- Dike reinforcement
- Construction of new quaysides or dikes
- Reducing the hydraulic load
- Building with nature solutions (such as lowering of groynes, deepening low flow channel etc.).

This study considers mainly the before mentioned type of measures. However, there are other possible measures that mainly reduce the consequences of a flood, such as (DPRD 2012):

- Influence the pattern of a flood
- Adaptive building (building on stilts, wet proof building, dry proof building, floating buildings)
- Protect critical infrastructure
- Risk zoning, prohibit building in areas with a high risk.
- Improving crisis management
- Development of an adaptive evacuation strategy
- Development of shelters, wide evacuation roads etc.

We will shortly describe the measures that are included in the economic analysis.

Adaptation Measure(s):

1. Dike reinforcement
2. Water storage Grevelingen
3. Room for the River measures
4. Channel deepening
5. Full closure with dams and sluices

*Dike reinforcement*

Rijnmond Drechtsteden will face an increased flood risk. Reinforcement of the dikes will lower this risk.

*Water storage Grevelingen*

The adaptation measure consists of opening of the Volkerak locks in case of high water levels (up to 2.6 meter above sea-level). Volkerak-Zoommeer & Grevelingen will be filled with water, which will slow down the rise of the water levels in other areas (see the green area of the figure below). This measure can only continue when the Measlant barrier is closed.

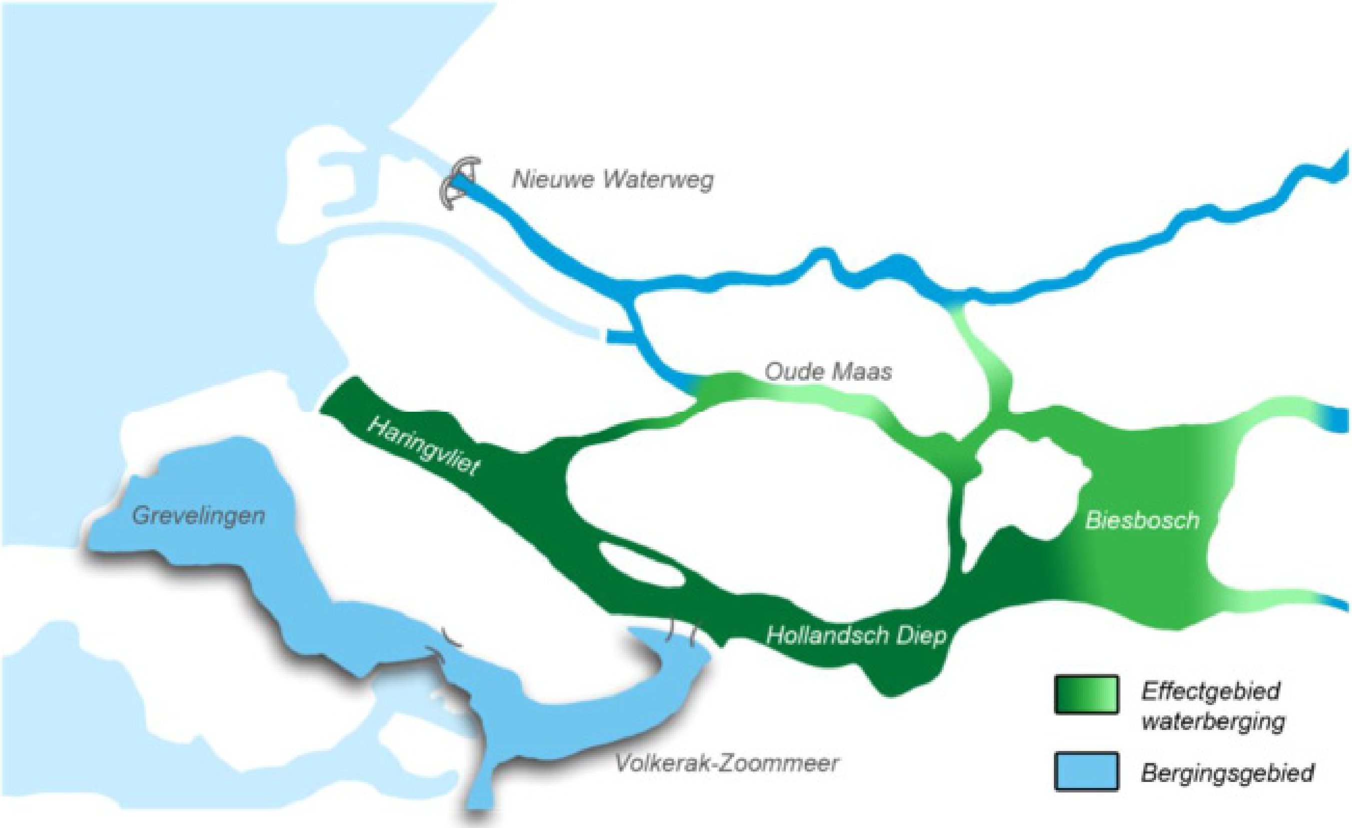



**Figure 6.18-5: Water storage Grevelingen**

*Room for the River measures*

The core of the room for the river measures is giving more space to the river in order to increase the velocity of the flow or to reduce the water level of excess flows and time of exposition to large floods. The figure below gives an overview of 8 different types of measures.

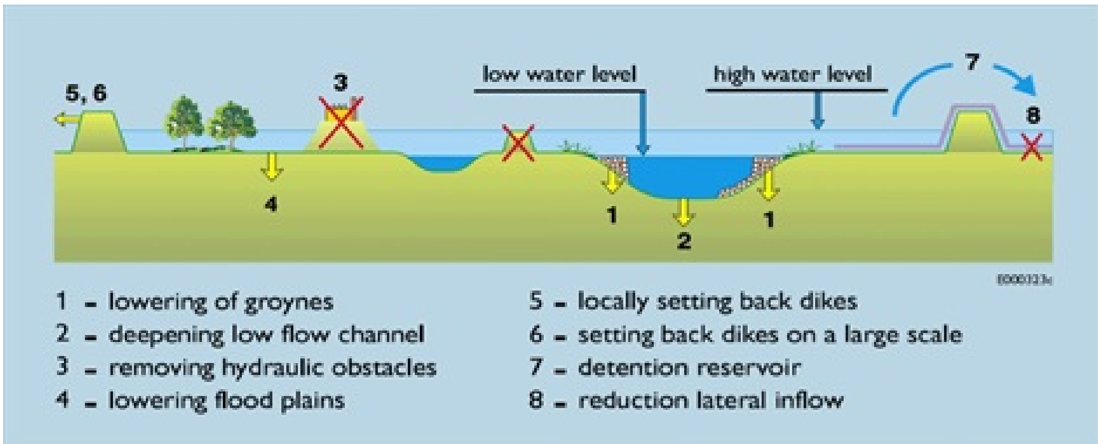



**Figure 6.18-6: Room for the River measures**
Source: Silva et al (2001)

In this case study these measures are categorized in four packages:

- Room for the River Small 1
- Room for the River Small 2
- Room for the River 3
- Room for the River 4

*Room for the River Small 1*

- Use of channel Steenenhoek, digging a channel through the Biesbosch and excavation of the straight spit of land in Gorinchem.

*Room for the River Small 2*

- Construction of a side channel close to Sleeuwijk and a flood plain excavation at the left side of the Boven Merwede in combination with the construction of a permeable abutment (bridge A27).
- Flood plain excavation at the right side of the Boven Merwede
- Dike relocation Werkendam along the left floodplain of the Boven Merwede in combination with construction of a side channel and creating a permeable channel (Beatrixport channel).

*Room for the River 3*

A combination of the measure Room for the River 1 and the following measures:

- Excavation of business area Avelingen along the right floodplain of the Boven Merwede in combination with construction of a permeable abutment (bridge A27) and excavation of the straight spit of land in Gorinchem.
- Construction of a channel through the Sliedrechtse Biesbosch on the left floodplain of the Boven Merwede in combination with a dike relocation in polder Hardinxveld along the right floodplain of the Boven Merwede.

*Room for the River 4*

A combination of the measures Room for the River 1 and Room for the River 2.

*Channel deepening*

Deepening of the summer beds of the new Merwede and Boven Merwede.

**Figure 6.18-7: Channel deepening**

*Full closure with dams and sluices*

This measure consists of full closure of the Nieuwe Waterweg aiming to lower the water levels in the area, resulting in less dike reinforcements and a reduced flood risk. The Nieuwe Waterweg will be closed with a lock complex including sea locks (green square), the Hartelchannel will be closed (at the location of Beerdam, red square) and extension of the Rozenburgsluice (blue dot).

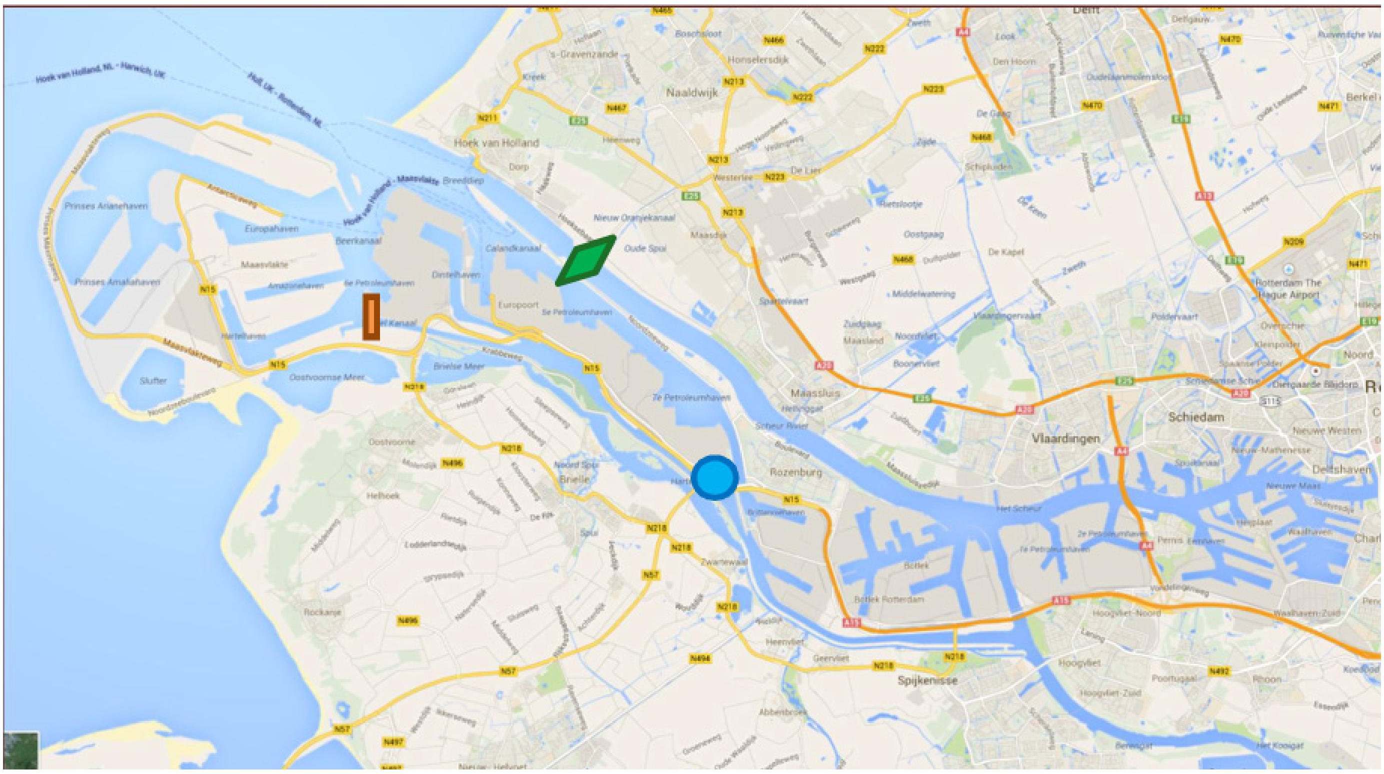



**Figure 6.18-8: Full closure with dams and sluices**

*Baseline option and complementary measures*

The baseline strategy consists of maintaining the current flood protection levels with dike reinforcement. This means that it includes current backlog. We have no insight in autonomous adaptation; therefore autonomous adaptation is not included in the baseline strategy.

The flood protection standards cannot be met without dike reinforcements. Therefore, the strategy will always consist of dike reinforcement whether or not combined with another measure. All the measures are complementary to each other.

**What are alternative adaptation pathways?**

If the measures are combined with sufficient dike reinforcements, all the measures will meet the objectives. Additionally, you can look to the sell by date of the individual measures. Kind et al. (2014) showed the different potential measures with indicative time window according to the Delta scenarios steam and rest. Although this gives an idea about the timespan of the different measures, it gives no indication of the ability to meet the defined objectives. Unfortunately, there is just a general prediction of the 'sell by date' of the individual measures (see the section time frame), since in the Netherlands these measures will be always combined with dike reinforcements.

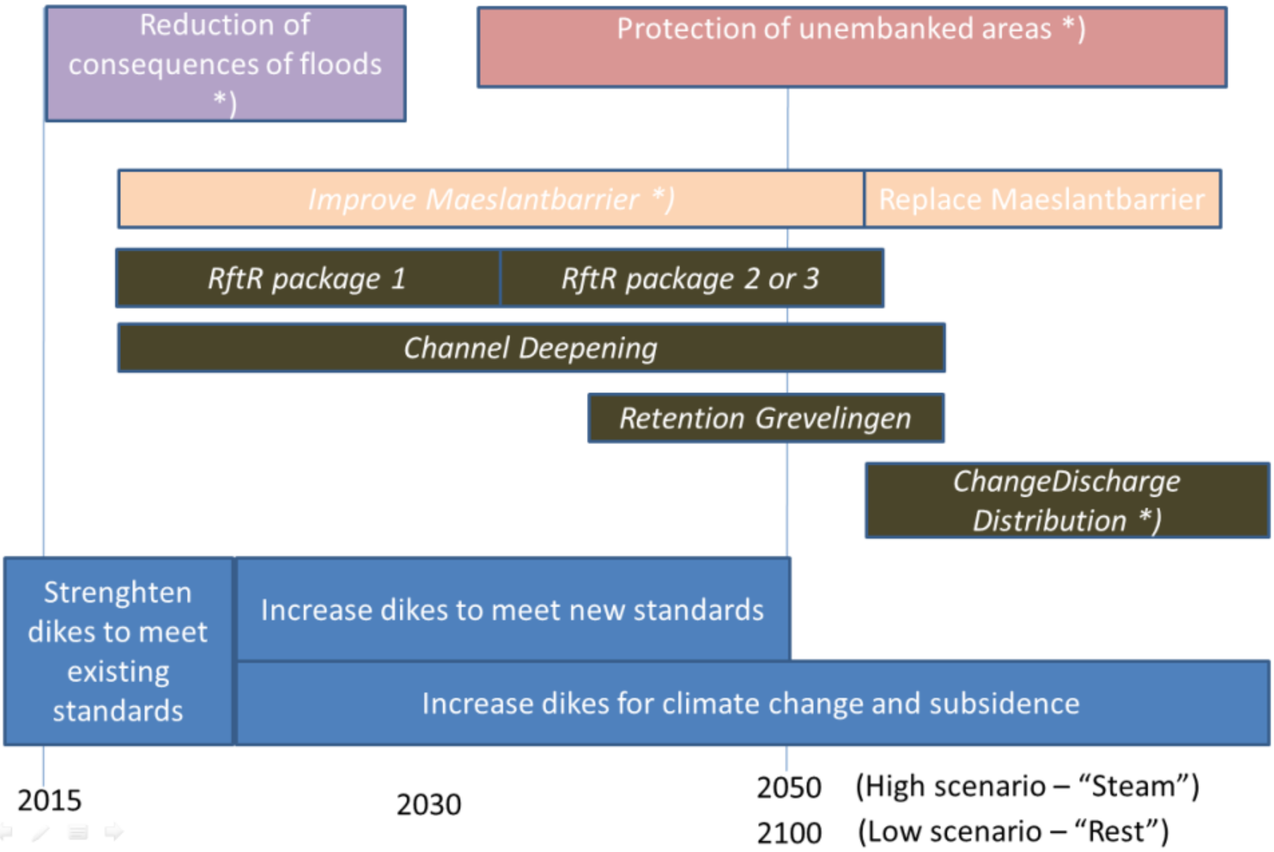



**Figure 6.18-9: Adaptation pathway**
Source: Kind et al (2014)

The Dutch Deltaprogramme made a pathway aiming to meet the flood protection standards until 2100. Figure 6.18-10 shows that dike reinforcement in combination with room for the river measures will meet the objectives until 2100 under a steam scenario. Under a rest scenario the objectives will even be met until 2150. Already in 2018 a decision will be made about whether or not implementing the measure 'discharge distribution' instead of more dike reinforcements (I&M 2014). Since both alternatives will be effective, this decision will not be based on the 'sell by date'.

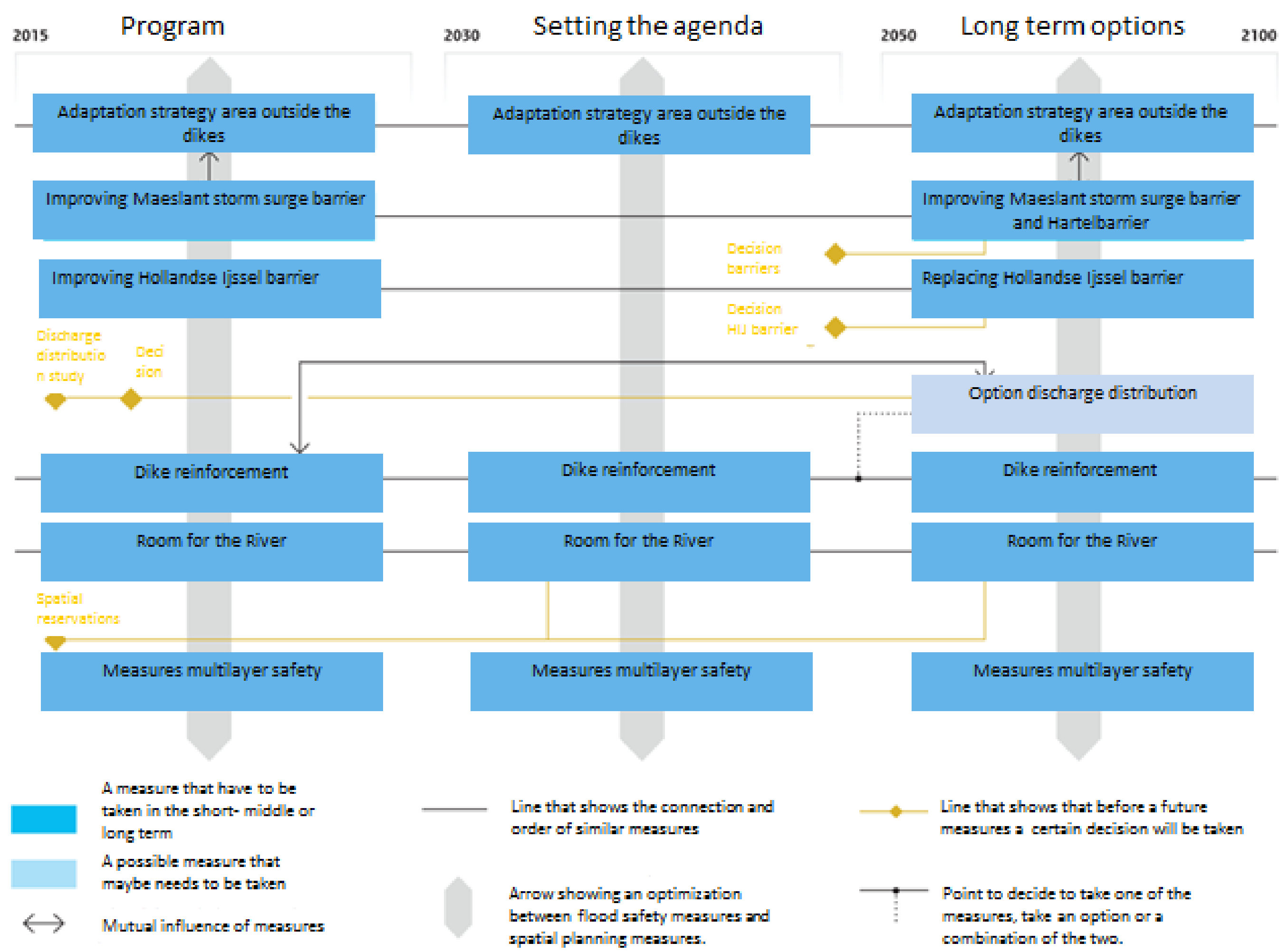



**Figure 6.18-10: Adaptation pathways developed by the Dutch Delta Program**
Source: I&M 2014

As mentioned before we cannot specify tipping points due to currently existing flood protection policy. The improvement or replacement of the Maeslant barrier is the only exception.

When comparing Figure 6.18-9 and Figure 6.18-10we see that the number of potential measures is higher than the measures finally included in the adaptation pathway of the Dutch Delta Programme. Alternative measures could be for example, channel deepening, water storage in the Grevelingen lake and full closure of the ‘Nieuwe Waterweg’ with dams and sluices. When considering the Maeslant barrier tipping point, the possible alternatives are improvement or replacement of the Maeslant barrier. Improving the barrier entails the same probability of failure as the current design, while replacement involves an upgrade to a lower probability of failure during closing (probably 1/1000). Although around 2070 the Maeslant barrier reaches its technical lifetime, in 2070 the functional life is not reached in a G scenario. Therefore, improvement will be more promising than replacement in a G scenario. In a W scenario the Measlant barrier can be kept as a barrier, but it can also be replaced by a dam or a sluice.

**Step 3 - Evaluation Criteria and Method**

**Which evaluation criteria should be used?**

First of all, we consider the investment and maintenance cost of the measure in the evaluation process. Secondly, we include the most important properties that can be affected by the measures. These have been limited to four categories:

- Flood risk
- Fresh water supply
- Disruption of shipping
- Nature

**What is the appropriate evaluation method?**

It is not possible to express all cost and benefit criteria in monetary terms. However, it is possible to express the effects on flood risk and disruption of shipping in monetary terms. Since reducing the flood risk is the main objective of the measures; we will complement the cost-benefit analysis by a multi criteria analysis. However, the results of this multi-criteria analysis are not yet presented in this CSLD.

**What are the preferences of stakeholders regarding the different evaluation criteria?**

Since fulfilling the flood protection standards is beneficial for all people in the region, flood risk is the most important evaluation criteria. A sufficient fresh water supply, which might seem beneficial for all stakeholders at first, is mainly beneficial for agriculture and in lesser extent industry, water companies and the shipping sector. The reason behind is the underlying Dutch policy. During periods of drought water is distributed based on the distribution priority sequence. Stability of the flood defences, the impact of drainage of peatlands, irreversible damage to nature, public water supply and energy supply are highly ranked at this sequence (Helpdesk water 2014). The Dutch drought problems will be not that widespread that there will be not enough water for this highly ranked functions. Therefore, mainly farmers will prefer the evaluation criteria fresh water supply. Concerning the evaluation criteria disruption of navigation, the stakeholders are skippers, skipper organisation and the industry dependent on shipping. The most important stakeholders for the evaluation criteria nature are nature organisations.

Since the multi-criteria analysis is a side analysis, we didn't consult stakeholders or experts to attach weights to the evaluation criteria. Therefore, we base the weights on the above mentioned analogy. We propose to use a weight of 4 for the criterion flood risk and 1 for the other criteria.

**Step 4 - Data collection**

**What are the costs and what are the benefits of the alternative adaptation options?**

We will use the Planning Kit DPRD for the analysis of the cost and benefits of the different adaptation options. The Planning Kit DPRD was developed as a decision support tool to evaluate a wide variety of flood risk management strategies. The Planning Kit computes on an annual basis the design water level and dike height, taking into account the effects of climate change and soil subsidence. For each year, the dike has to withstand the dike height test. When a dike fails this test, the dike is heightened[88]. To determine the amount of necessary dike heightening, a design horizon of 50 years is used, starting from the year of rejection. This means that after heightening, the dike has to withstand the dike height test for 50 years after the rejection, taken into account projections of climate change and soil subsidence (Kind et al. 2014). Since dike reinforcement is not the only possible measure to fulfil the objective, additional measures can be included. For example measures that will lower the design water levels, such as room for the river measures. Incorporating these measures will lower the design water level, causing the dike to pass the dike height test longer. However, measures lowering the design water levels will never make dike

[88] A dike is heightened after a lead time of 15 years. This has been included to accommodate for the time laps between rejection and reinforcement of a dike, due to policy decisions, design of the reinforcements, procurements, etc.

reinforcements redundant. The tool determines nominal and present values of all costs of measures and the present value of the benefits of the measures (Kind et al. 2014).

*Costs*

The planning kit includes the costs of dike reinforcements and the costs of other measures. Therefore, we will first consider the costs of dike reinforcement and then the costs of other measures.

The costs of the dike reinforcements are based on the model KOSWAT (Grave & Baarse 2011). This model estimates cost curves for every dike section. At first the model applies the latest insights in failure mechanisms, after which the costs are determined to heighten the dike. Step by step the dike is heightened with stages of 10 centimetre with a maximum of 2 meter. After every step the model estimates if the dike is high enough to fulfil the flood protection standards. Every step consists of fixed costs and variable costs (depending on which step). The fixed costs include e.g. replacement of infrastructure on the crest of the dike and aesthetic finishing (Kind et al. 2015).

The costs of additional maintenance due to the heightening of the dikes are presented through a percentage of the yearly investment costs. This percentage generally lies between 0 and 0,2 per cent. In this analysis, we decided to include a percentage of 0 per cent (Kind et al. 2015).

Additionally, we assume that costs increase by 33 per cent if a dike is heightened that was already heightened[89] before (Fiselier & Prins 2007).

Costs of other measures are based on estimations of the 'Centre of Expertise on Costs and Benefits' of the Delta Programme. We calculate the net present value of the costs with the formula:

NPV = NPV investment * (1+(management and maintenance costs as yearly per cent of the investment/discount rate))

**Table 6.18-1: Costs of measures (different as dike reinforcement)**

| Description | Costs (mln EUR) | Operation & Maintenance costs (% each year) |
|---|---|---|
| Replacement Maeslant barrier in 2070 | 956 | 0,82 |
| Partial performance Maeslant barrier | 20 | 10,00 |
| Room for the River small 1 | 38 | 0,77 |
| Ruimte voor de river small 2 | 545 | 0,28 |
| Ruimte voor de rivier small 3 | 455 | 0,40 |
| Water storage Grevelingen | 263 | 0,38 |
| Local evacuation strategy | 3 | - |
| Channel Deepening | 98 | 2,91 |
| Variant Spaargaren 1 Afgesloten zeezijde bij Maeslantkering | 2430 | 0.03 |

Source: Prins (2013), Kind et al (2015).

[89] By at least 1 meter

*Benefits*

The Planning Kit computes the expected flood damages in the area on an annual basis. We take the reduction of the expected flood damages as the main benefit. Our flood damage calculation includes:

- Causalities
- People affected
- Property damages (residential properties including vehicles, businesses)
- Infrastructure
- Agriculture
- Utility companies
- Loss of added value due to (temporary) closure of businesses
- Indirect damages

The information on damages and causalities is based on approximately 110 inundation scenarios (Kind 2013; Eijgenraam et al. 2014). The damage depends on the Delta scenario chosen for the calculation (e.g., Steam or Rest).

We used the value of a statistical life (6,7 m EUR) to value the causalities. This amount includes a premium for people injured. We valued the intangible damage of people affected on 12.000 EUR per person including a premium for evacuated people (Kind 2011).

**What is the evaluation time frame?**

The measures can be assumed for implementation at any year in the period 2017-2100. Although dike reinforcements have a design horizon of 50 years, the actual lifetime is longer due to the additional allowance for robustness of 30 cm. The lifetime of a new Maeslant barrier will be 100 years. Also room for the river measures have an expected lifetime of 100 year. However, the lifetime depends on the amount of management and maintenance.

Residual value: Measures taken just before 2100 with a remaining lifetime after 2100 lead to increased safety for a certain period before 2100, but also afterwards. Therefore, we calculate the residual risk for the period 2100-2150 for all strategies in the Planning Kit. An important assumption is that in the period after 2100 nothing will change (no further investment, no growth, no increase in the probability of flooding). The expected flood damage for the period 2100-2150 is then also discounted to the year 2015 and added to the estimated flood damage for the period 2015-2100.

**Which discount rate should be applied?**

For discounting costs and benefits, we use the 5.5% real discount rate per year, as prescribed by the Dutch government. Although we would like to include a lower discount rate in the sensitivity analysis, there was no time available for a recalculation of the results.

**How to deal with data uncertainty?**

We didn't include uncertainties related to the performance of the measure. However, we included scenarios to show the different performances of the measures. Additionally, we choose different years to implement the measure. Both are influencing the performance of the measure and showing some of the uncertainties decision makers have to take into account.

**Step 5 – Evaluation and Prioritization**

**What is the ranking order of alternative adaptation options (measures, bundles of measures or pathways)?**

One of the aims of this study was applying a cost benefit analysis to create efficient[90] adaptation pathways. Therefore, we derived the costs and damages of the alternative options from the planning kit DPRD (Kind et al. 2015). The planning kit assumes that the flood protection standards are always met. For example, the reference situation meets the flood protection standards just with dike reinforcements. If another measure is taken, for

[90] We define efficient as achieving the goal with minimum effort or expenses. In this case minimum expenses comprise minimum remaining damage.

example room for the river 1, the remaining task is met with additional dike reinforcements. Recall that the estimates including costs of the measure and remaining damages due to flooding, other benefits of the measures such as benefits for nature, shipping or recreation are not considered. See chapter 5d for a more extensive explanation of the planning kit.

The results of the analysis are presented in Table 6.18-1 and Table 6.18-2. The present value includes cost of the measure (including remaining dike reinforcement) and the remaining damage. We assume that a measure could be implemented at any time. However, we could not estimate the present value for all possible years of implementation. Therefore we estimated the present value for implementing the measure in the years 2030, 2040, 2050, 2060 and 2070. Improvement of the Maeslant barrier is always included in the Steam scenario, because in a steam scenario a tipping point is reached in 2070, while in a rest scenario this is attained much later (Kind et al. 2014).

When comparing Table 6.18-1 and Table 6.18-2, we see that the difference between the scenarios is approximately 500 m EUR.  For the rest scenario the costs ranges between 3.03 and 3.81 bn EUR, while for the steam scenario it ranges between 3.56 and 4.28 bn.  Both the improvement of the Maeslant barrier and the higher difficulty to meet the flood protection standards in the steam scenario may cause this difference. The relative small difference between the scenarios is because in each scenario the majority of the dike reinforcements are needed to meet existing and future flood protection standards (Kind et al. 2014). Room for the river small 1, the reference and channel deepening are in both scenarios the strategies with on average the lowest present value.

**Table 6.18-2: Present value for scenario Rest in m EUR**

| Strategy | 2030 | 2040 | 2050 | 2060 | 2070 |
|---|---|---|---|---|---|
| Reference | 3042 | 3042 | 3042 | 3042 | 3042 |
| Room for the River small 1 | 3033 | 3036 | 3032 | 3030 | 3043 |
| Room for the River small 2 | 3261 | 3165 | 3105 | 3070 | 3071 |
| Room for the River 3 | 3257 | 3173 | 3110 | 3086 | 3070 |
| Room for the River 4 | 3250 | 3162 | 3099 | 3063 | 3072 |
| Water storage lake Grevelingen | 3129 | 3102 | 3072 | 3055 | 3054 |
| Full closure with dams & sluices | 3811 | 3543 | 3322 | 3209 | 3150 |
| Channel deepening | 3060 | 3051 | 3036 | 3031 | 3048 |
| Combination of 2+3 | 3457 | 3294 | 3177 | 3121 | 3098 |

**Table 6.18-3: Present value for scenario Steam in m EUR**

| Strategy | 2030 | 2040 | 2050 | 2060 | 2070 |
|---|---|---|---|---|---|
| Reference | 3574 | 3574 | 3574 | 3574 | 3574 |
| Room for the River small 1 | 3562 | 3572 | 3568 | 3566 | 3574 |
| Room for the River small 2 | 3787 | 3702 | 3642 | 3606 | 3603 |
| Room for the River 3 | 3787 | 3702 | 3645 | 3611 | 3603 |
| Room for the River 4 | 3762 | 3702 | 3639 | 3603 | 3603 |
| Water storage lake Grevelingen | 3619 | 3608 | 3580 | 3565 | 3570 |
| Full closure with dams & sluices | 4282 | 4074 | 3837 | 3716 | 3678 |
| Channel deepening | 3588 | 3589 | 3574 | 3565 | 3578 |
| Combination of 2+3 | 3984 | 3913 | 3856 | 3823 | 3813 |

Since we want to compare the measures, we deduct the strategies from the reference strategy. The results show that only 'room for the river 1' and in some years 'channel deepening' are alternatives for the reference strategy. Additionally, 'water storage Grevelingen' can be a reasonable alternative in a steam scenario. Notable is that the present value becomes smaller if the measure is implemented later in time. This is due to the high discount rate and the fact that dike reinforcements in the reference situation are always implemented in the year 2032. The figure shows that full closure of the 'Nieuwe Waterweg' and a combination of room for the river 2+3 are the least favourable options based on the costs and damage due to flooding.

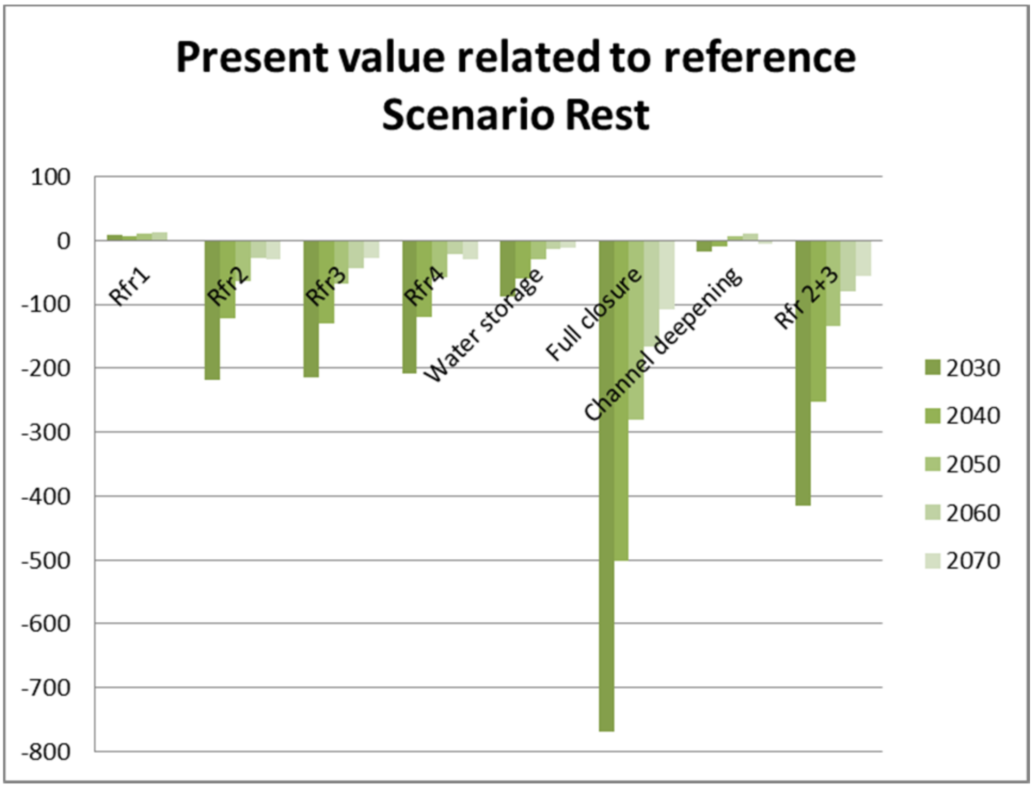



**Figure 6.18-11: Present value of the measures minus the present value of the reference scenario in m EUR for scenario Rest**

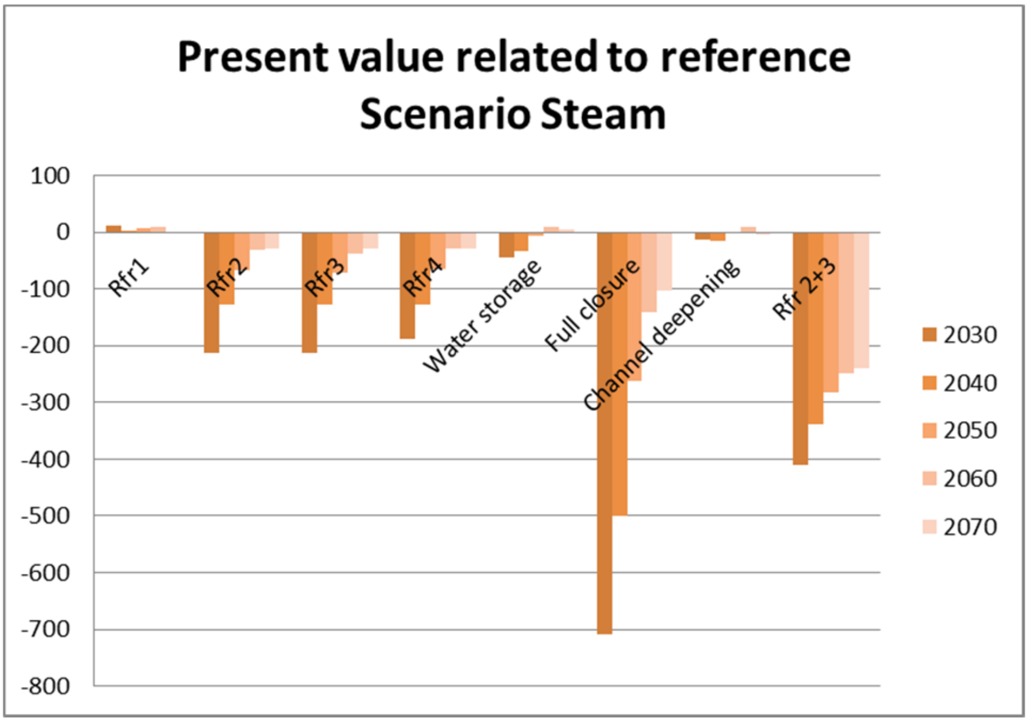



**Figure 6.18-12: Present value of the measures minus the present value of the reference scenario in m EUR for scenario Steam**

Based on the costs and remaining damages of the strategies we are able to analyse the costs and benefits of individual strategies. We distinguish two types of benefits of the measures. First is the reduction in the present value of the cost of dike reinforcements. This benefit arises since investments in dikes are postponed as a consequence of water level reducing measures. The second benefit is the reduction in the present value of the expected damages. This benefit arises only when measures are implemented relatively early, before a dike, which has a positive water level reducing effect from the measure has failed the height test. This will lead to temporarily excesses (above the legal standard) in flood protection for certain dikes, and hence to a further reduction of the expected damages (Kind et al. 2014). The reduction in expected damage is about 10 per cent of the total benefits. However for each measure this largely varies.  We calculated benefit-cost ratios by dividing the total of the two types of benefits by the cost of the measures. The results show that room for the river 1 and channel deepening are the strategies with a positive b/c ratio in a rest scenario, while in a steam scenario the b/c ratio of channel deepening decreases and water storage Grevelingen becomes positive (see Figure 6.18-13 and Figure 6.18-14). The other strategies have on average really low b/c ratios. Recall that a benefit-cost ratio is a ratio. For example, a benefit of 6 EUR and an additional cost of 2 EUR result in a ratio of 3, while a benefit of 60 m and additional costs of 20 m EUR also result in a ratio of 3. Therefore, the ratios have to be compared with absolute numbers.

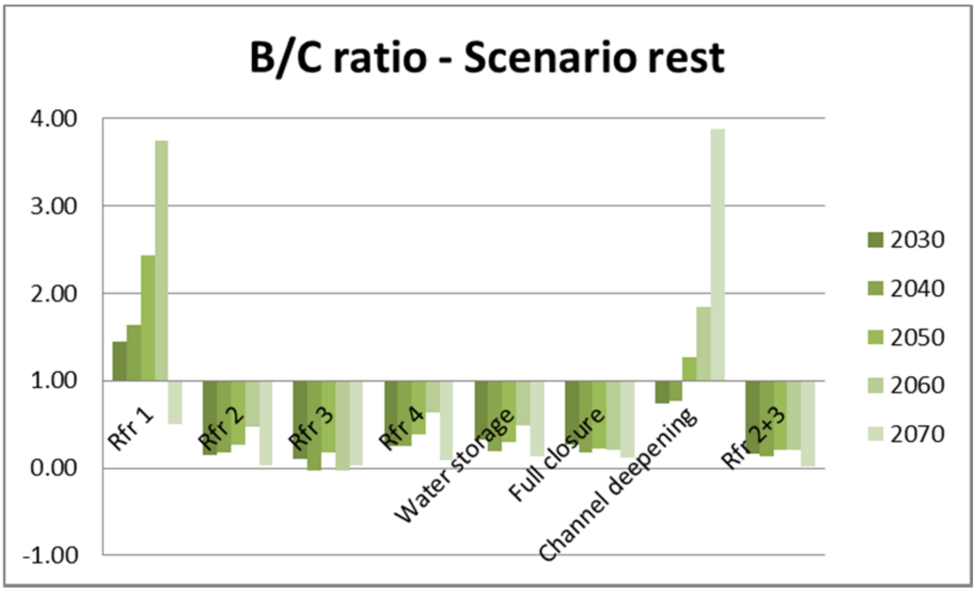



**Figure 6.18-13: Benefit cost ratio in Scenario Rest**

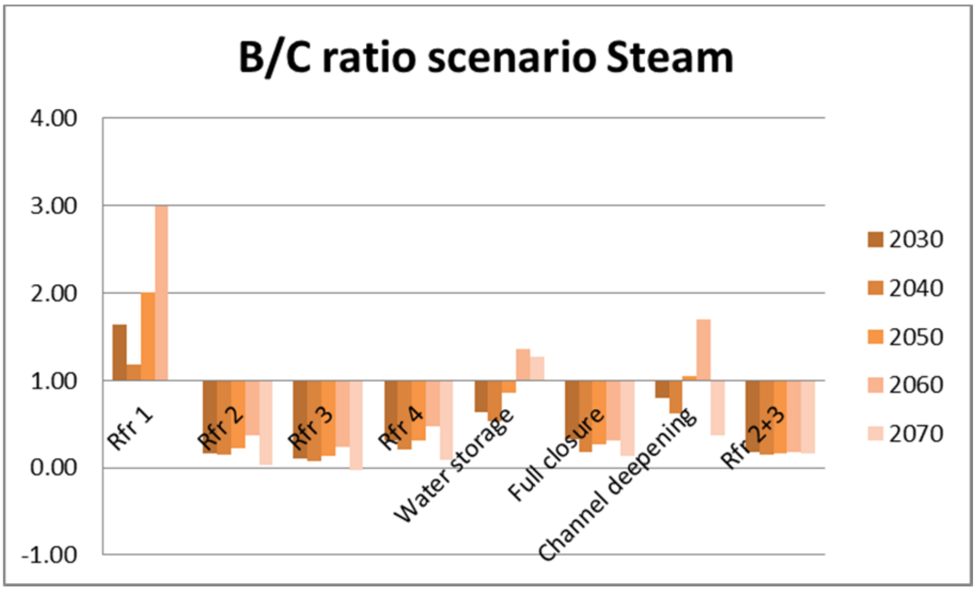



**Figure 6.18-14: Benefit cost ratio in Scenario Steam**

With these results we made adaptation pathways based on costs and benefits, which may support policy makers in making decisions under uncertainty. These adaptation pathways are not based on the effectiveness of the strategies, since we assume that all strategies will meet the same flood protection standards, but on the costs and benefits to reach the flood protection standards. We consider that the most efficient pathways are the pathways with the lowest present value. Subsequently, the tipping points can be defined as the point where the current management strategy is no longer the most efficient one. Since we did not include all the benefits in the estimation, we do not assume that there is one most optimal pathway. Therefore, we included all strategies differing less than one per cent from the reference strategy. Each year a strategy has the lowest present value, we consider these strategies together as the most efficient pathway (see Figure 6.18-15 and Figure 6.18-16). A similar approach was taken for the second and third most efficient pathways.

**Table 6.18-4: Present value rest scenario in m EUR**

| Strategy (rest) | 2030 | 2040 | 2050 | 2060 | 2070 |
|---|---|---|---|---|---|
| Reference | 3042 | 3042 | 3042 | 3042 | 3042 |
| Room for the River small 1 | 3033 | 3036 | 3032 | 3030 | 3043 |
| Room for the River small 2 | 3261 | 3165 | 3105 | 3070 | 3071 |
| Room for the River 3 | 3257 | 3173 | 3110 | 3086 | 3070 |
| Room for the River 4 | 3250 | 3162 | 3099 | 3063 | 3072 |
| Water storage lake Grevelingen | 3129 | 3102 | 3072 | 3055 | 3054 |
| Full closure with dams & sluices | 3811 | 3543 | 3322 | 3209 | 3150 |
| Channel deepening | 3060 | 3051 | 3036 | 3031 | 3048 |
| Combination of 2+3 | 3457 | 3294 | 3177 | 3121 | 3098 |

Note: The green PVs differ less than 1% different from the reference.

**Table 6.18-5: Present value steam scenario in m EUR**

| Strategy (rest) | 2030 | 2040 | 2050 | 2060 | 2070 |
|---|---|---|---|---|---|
| Reference | 3574 | 3574 | 3574 | 3574 | 3574 |
| Room for the River small 1 | 3562 | 3572 | 3568 | 3566 | 3574 |
| Room for the River small 2 | 3787 | 3702 | 3642 | 3606 | 3603 |
| Room for the River 3 | 3787 | 3702 | 3645 | 3611 | 3603 |
| Room for the River 4 | 3762 | 3702 | 3639 | 3603 | 3603 |
| Water storage lake Grevelingen | 3619 | 3608 | 3580 | 3565 | 3570 |
| Full closure with dams & sluices | 4282 | 4074 | 3837 | 3716 | 3678 |
| Channel deepening | 3588 | 3589 | 3574 | 3565 | 3578 |
| Combination of 2+3 | 3984 | 3913 | 3856 | 3823 | 3813 |

Note: The green PVs differ less than 1% different from the reference.


**Figure 6.18-15: Economic efficient pathways in a rest scenario**

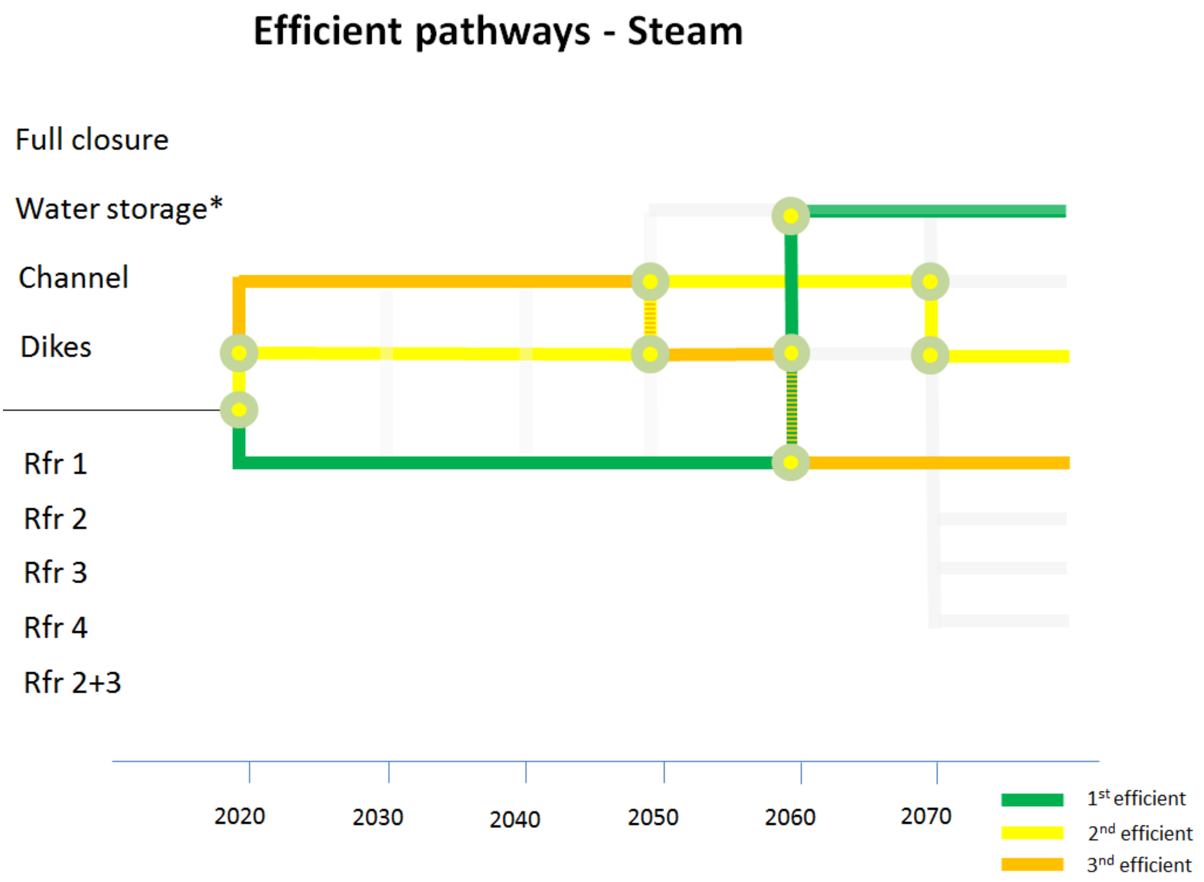



**Figure 6.18-16: Economic efficient pathways in a steam scenario**

Figure 6.18-15 and Figure 6.18-16 show that until 2050 the pathways are the same in both scenarios, after this year the pathways start to differ. For example, in 2060 in a steam scenario water storage is the most efficient pathway, while in a rest scenario water storage is not even one of the three most efficient pathways.

The pathways give policy makers an indication of the options from a perspective of cost and benefits. However, policy makers want to make a decision that they will not regret. Therefore, we combined the two pathways into one pathway. We did this in two ways by just superimposing the pathways on one another and by summing the present value of both scenarios for each strategy. We indicated strategies that differ less than one per cent from the reference strategy. In Figure 6.18-19 all pathways are combined, which shows a complete but slightly unclear image. Figure 6.18-20 includes the strategies presenting the lowest total present value, which results in a clearer overview of the pathways. Besides showing all the strategies differing less than one per cent, we made pathways that show all the strategies differing less than five per cent from the reference strategy. This illustrates that the differences between strategies become much smaller during time. Finally, we made a pathway summing all the most efficient pathways of the before mentioned pathways. Although the advantage is that the image becomes clearer, the disadvantage is that good scores of both channel deepening and dikes (reference) are not presented in the image. Showing just this pathway will provide policy makers with incomplete information, which may result in suboptimal choices.  Therefore we state that this type of pathway always have to be shown in combination with preferably combined 2 or combined 5%.

**Table 6.18-6: The present value in both scenarios (PV in steam plus PV in rest)**

| Strategy (rest) | 2030 | 2040 | 2050 | 2060 | 2070 |
|---|---|---|---|---|---|
| Reference | 6616 | 6616 | 6616 | 6616 | 6616 |
| Room for the River small 1 | 6595 | 6608 | 6600 | 6596 | 6617 |
| Room for the River small 2 | 7048 | 6867 | 6747 | 6676 | 6674 |
| Room for the River 3 | 7044 | 6875 | 6755 | 6697 | 6673 |
| Room for the River 4 | 7012 | 6864 | 6738 | 6666 | 6675 |
| Water storage lake Grevelingen | 6748 | 6710 | 6652 | 6620 | 6624 |
| Full closure with dams & sluices | 8093 | 7617 | 7159 | 6925 | 6828 |
| Channel deepening | 6648 | 6640 | 6610 | 6596 | 6626 |
| Combination of 2+3 | 7441 | 7207 | 7033 | 6944 | 6911 |

Note: The green PVs differ less than 1% from the reference, the red numbers differ more than 5% from the reference.

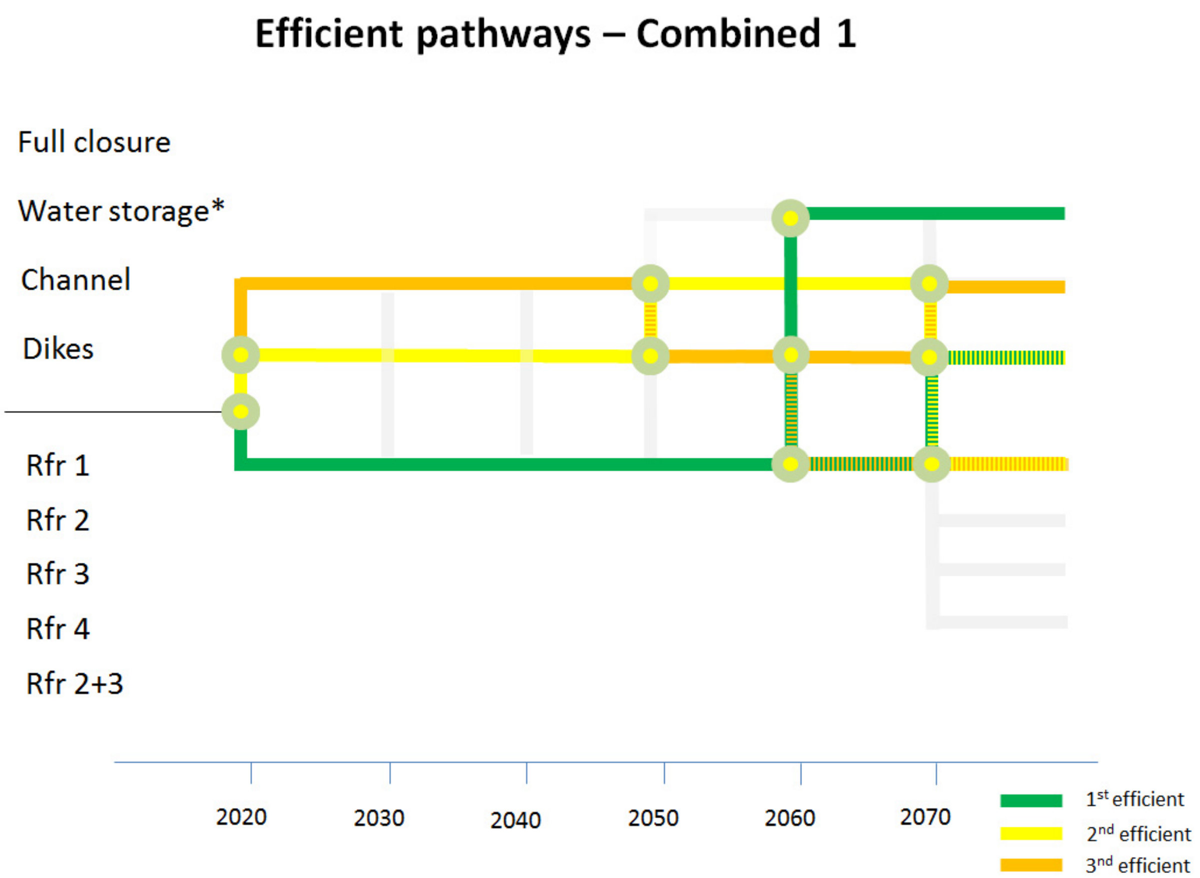



**Figure 6.18-17: A combination of the most efficient pathways for steam.**

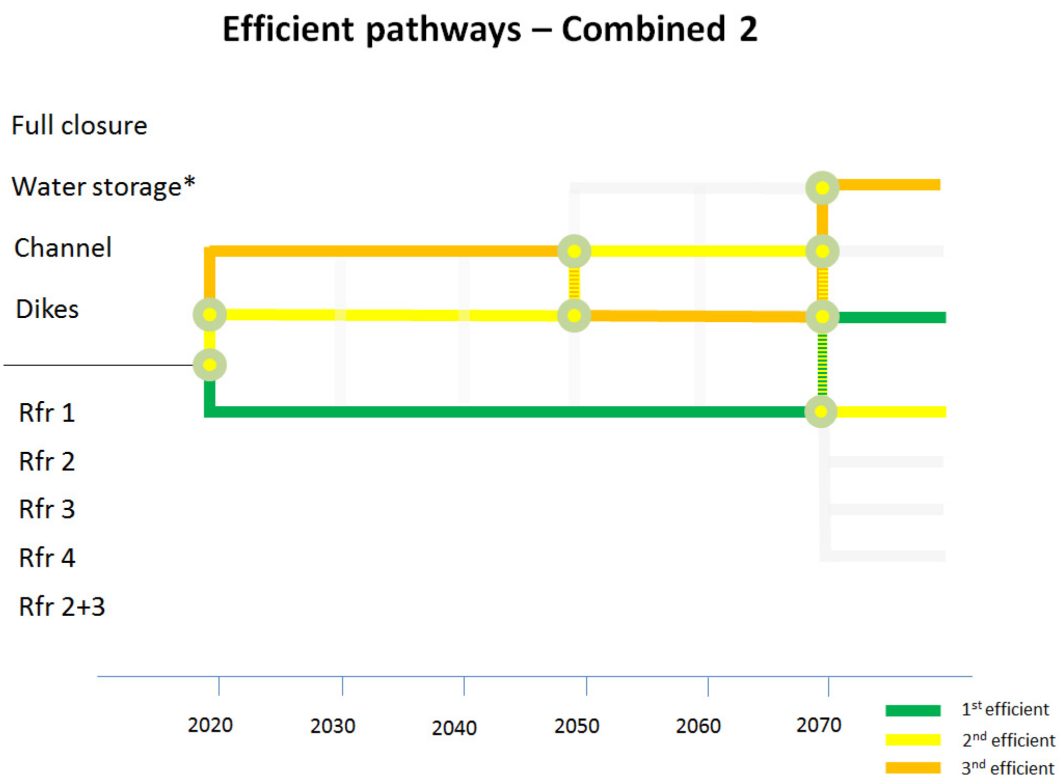



**Figure 6.18-18: A combination of the most efficient pathways for rest.**

The first figure shows a combination by superimposing the two pathways and the second figure shows construction of new pathways from the sum of the present values of a steam and rest scenario.

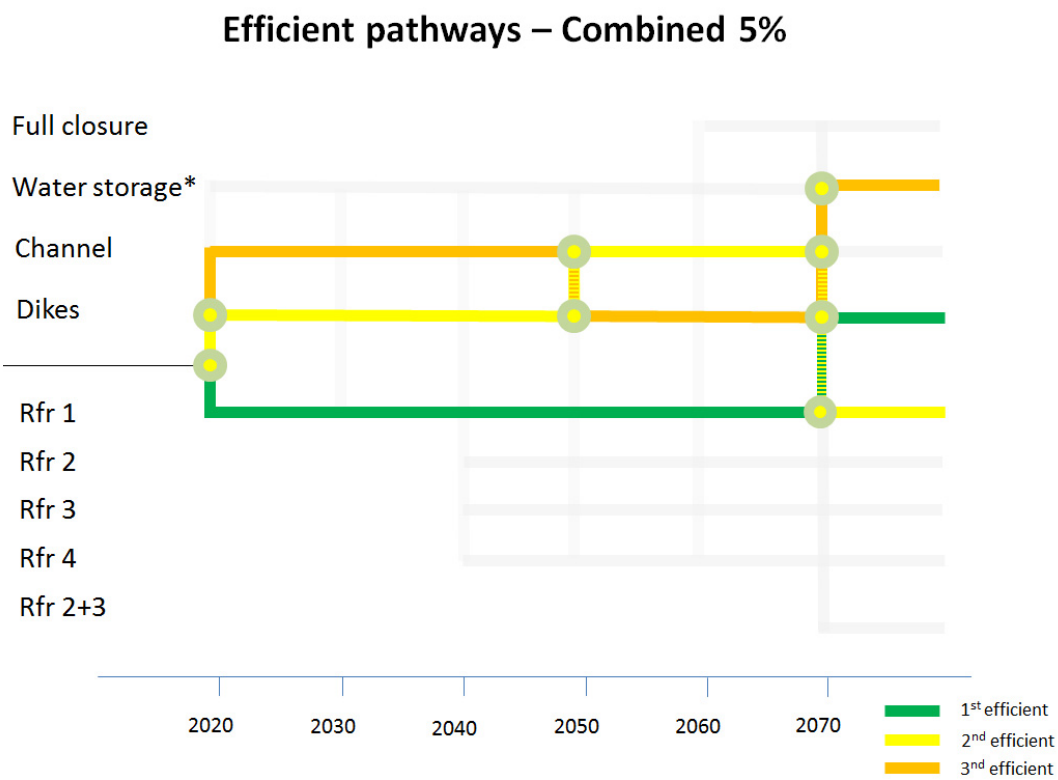



**Figure 6.18-19: Pathways that differ less than 5% of the reference strategy**

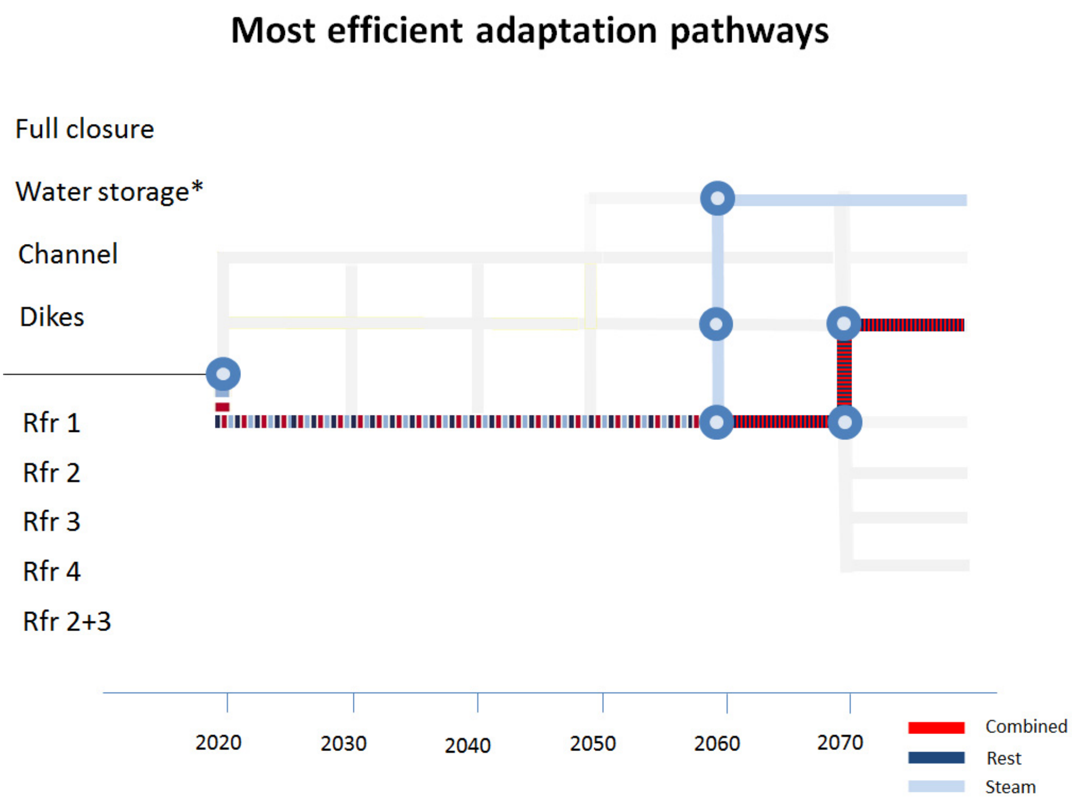



**Figure 6.18-20: The most efficient pathways according to the analysis.**

Decision makers want to make the best possible choice. However, all the possible uncertainty has to be eliminated to make this best possible choice. Since, it is not possible to eliminate all uncertainty, handling uncertainty the best possible way is a good alternative. The efficient pathways help policy makers to better deal with this uncertainty. The strategies having a similar result in both scenarios comprise less uncertainty than others. From the perspective of efficiency, these strategies are more favourable than others. Figure 6.18-21 shows that room for the river 1, 2 and 3 and channel deepening have the smallest spread between the scenarios, while water storage Grevelingen, full closure and a combination of room for the river 2 and 3 have a large spread. Although water storage is in the pathways approach one of the more efficient options, considering the wide spread between the scenarios, this strategy is less favourable for decision makers. Since this has to be taken into account, we choose to indicate this with an asterix in the pathway figures.

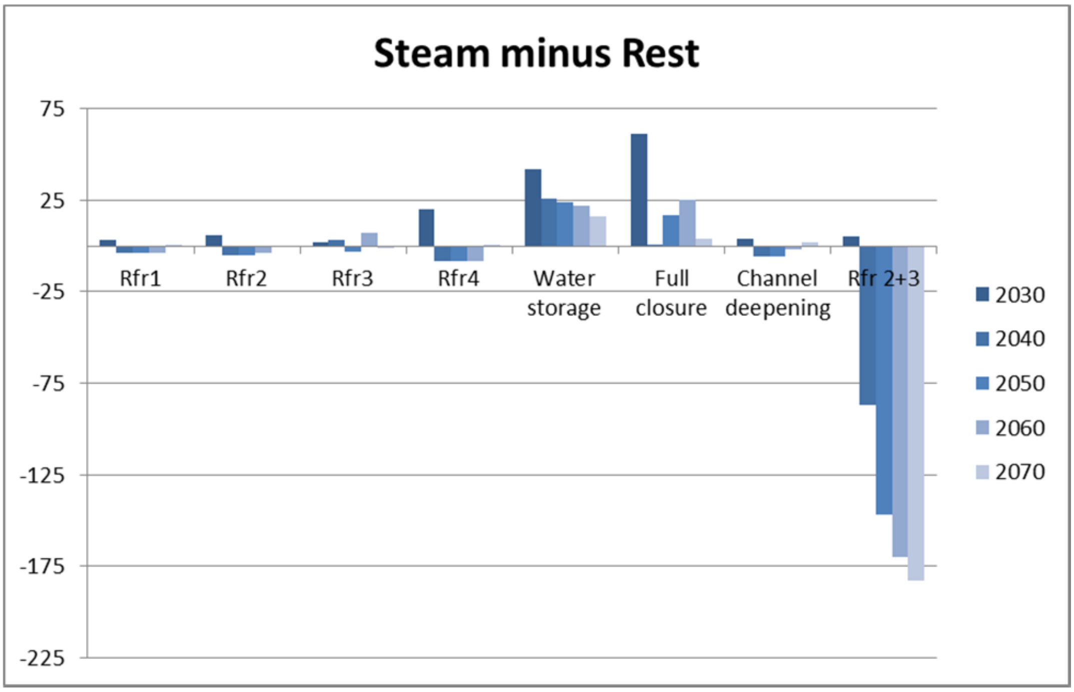



**Figure 6.18-21: Difference between steam and rest scenario in m EUR.**

The pathways are based on costs and avoided damages of different strategies. We did not include benefits different than avoided damages. However, in theory a cost-benefit analysis includes all benefits. Therefore, we conducted a multi-criteria analysis using the program Primate. In this MCA we included effects on ecology and shipping. These effects are based on expert judgments. Since not all the benefits seem to be even as important, different weighing factors are applied. Avoided damage and costs get a weighing factor of 4, while ecology and shipping got both a weighing factor of 1. These factors are also based on expert judgment. The results show that room for the river is still the most preferred option, followed by channel deepening, dike reinforcement and water storage. However, the analysis shows as well that there is a large variety in the rank of the different options. For example, water storage has both rank number 1 and rank number 4. This is probably due to the large spread between the scenarios. The small difference between the results of the cost-benefit analysis and the MCA may be caused by the small difference between the scores on ecology and shipping for the different strategies and by the low weighing factor of the ecology and shipping indicators.

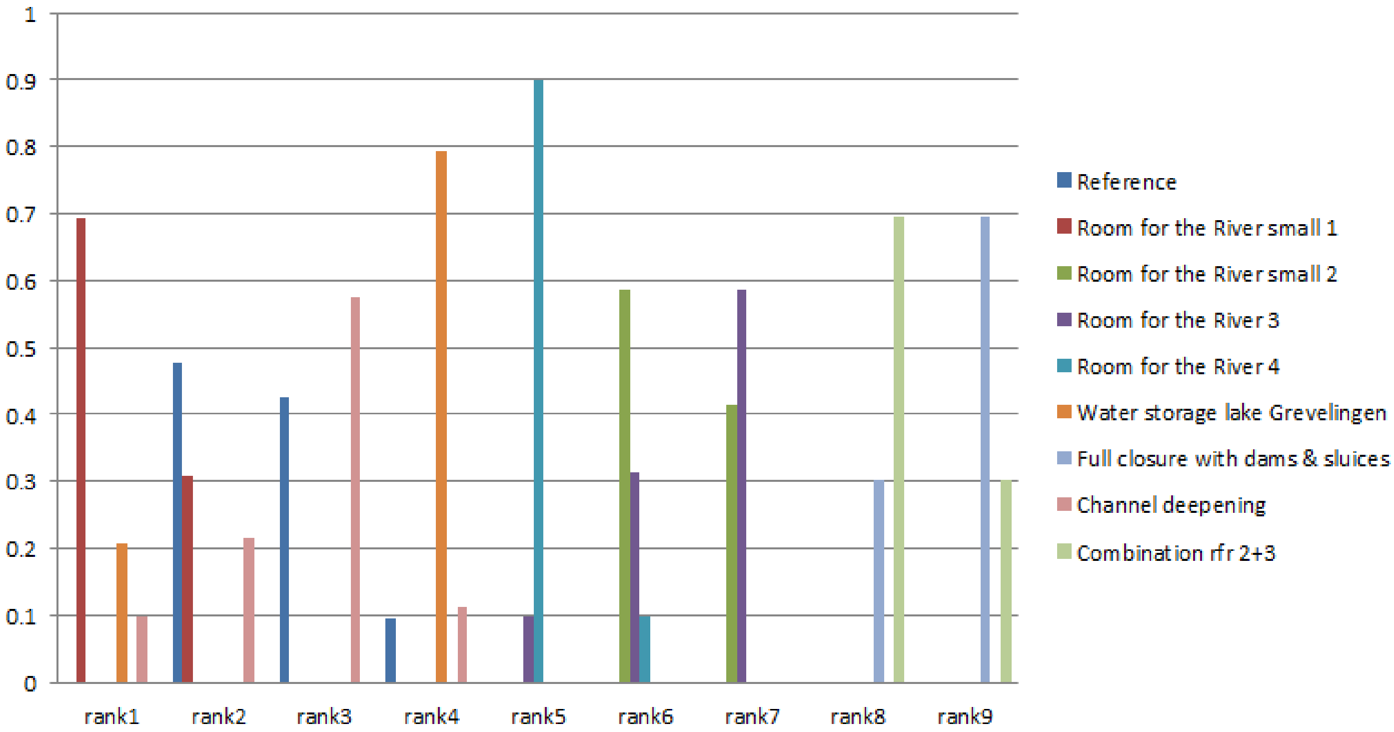



**Figure 6.18-22: MCA results**

## What are the main lessons learnt from your case study?

**Transferable results**

Although, the method that we used is transferable to other case studies, the results are not easy transferable to other areas. The main reason is that the Dutch situation is very different to situations in other countries. The Netherlands has strict flood protection standards and an extensive dike network. Therefore, the proposed adaptation measures and their effect may deviate from flood adaptation measures in other countries. For example, in the Netherlands the costs of dike reinforcement is most of the time smaller than the costs of other measures, while in countries without an extensive dike infrastructure, these measures may be more expensive than other flood protection measures. Although the transferability is limited, some general statements can be made about flood protection measures. For example, the results show that the costs and benefits of other measures than dike reinforcement are nearly always higher than dike reinforcement in the Netherlands. This result can be probably transferred to areas with a extensive dike infrastructure. In addition, even though the results are not easy transferable, the efficient pathways method can easily be transferred.

**Feasibility of methods**

The evaluation of costs and benefits with the 'Planning kit DPRD' is a rather new way of estimating costs and benefits of flood protection measures. However, it is based on the basic assumptions of cost-benefit analysis. The construction of efficient adaptation pathways seems to be a simple exercise in a situation with an already existing service level (f.e. flood protection standards). However, the method has still to be optimized and the usefulness has to be demonstrated. The approach of this case study is best applicable in cases with an agreed upon service level.

**Important data sources**

The most important data in this case study were:

- Costs estimates of dike reinforcements for different years and costs of other measures
- Necessary dike reinforcements to meet the flood protection standards

- Flood damage data including casualties, people affected, property damages, damages to infrastructure, agriculture and utility companies, loss of added value due to closure of businesses and indirect damage.

**Recommendation to improve the efficient pathway approach.**

The efficient pathways consist of strategies that can be implemented in a certain year, it shows which strategy can be best chosen from a perspective of cost and benefits at a certain year. In addition, it shows which options are relevant for the long term from a cost benefit perspective. The approach does not yet include path-dependency or flexibility of strategies in the pathways. This has to be further investigated. In this analysis we choose to not combine strategies to make the analysis not too comprehensive. However, we analysed one combination of strategies to test the applicability of the efficient pathway approach. The results showed that combining strategies may higher or lower the costs or benefits more than just the sum of two strategies (see the combination of strategy room for the river 2 and 3). Combination of strategies may add efficient options for policy makers, potentially with lower costs and benefits than the individual strategies. However, a combination of strategies requires a new estimation of the costs and benefits of combined strategies, which also requires creation of new pathways that show the most efficient combination of strategies. Also recall that not all strategies in this analysis can be combined with other measures, for example the strategy ‘just dikes’ has this limitation. After implementing a strategy different than ‘just dikes’ returning to ‘just dikes’ is not possible until at least the year 2100, due to the expected lifetime of 100 year of most strategies.

The efficient pathways consist of all the strategies differing up to 5 per cent from the reference strategy, implying that the performance of these strategies is not significantly different. However, in this early stage of the decision making process the uncertainty margin of the cost and benefit estimation is approximately 30 per cent (Fiselier & Prins 2007). This calls for pathways including strategies differing up to 30 per cent from the reference strategy. However, the costs of strategies include the costs of dike reinforcement needed to meet the current flood protection standards, while this are not costs of adaptation to climate change. In a further analysis these costs have to be deducted from the total costs, which will affect the percentages (and the significance levels).

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## 6.19 Cornwall

Sahran Higgins, Tim Taylor, University of Exeter

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

**What is the climate change related problem/risk you would like to reduce by adaptation?**

Climate change may have significant adverse impacts on human health (IPCC 2007). Consequently, increasing attention is now being given to the issue of adaptation (IPCC 2007; Stern 2007; Costello et al. 2011). The effects of anthropogenic climate change have been discernible for a number of years (WHO 2009a). Most people will have noticed changes to the weather (Kerr 2011) and in the timing of seasonal events such as earlier flowering (Fitter and Fitter 2002). Weather anomalies and extreme events are becoming more frequent globally (e.g. heatwaves and flooding). Over the coming decades, societies will need to adapt to the changing climate (Stern 2007) based on local requirements. Climate change adaptation in terms of minimising or avoiding human health impacts is now taking centre stage (Kurane 2009; Bell 2011). Improvements in the resilience of healthcare systems to meet future climate change will save money long-term and will also assist in coping with natural catastrophes. The World Health Organization (WHO) and the European Commission are both funding research aimed at facilitating health adaptation to climate change (WHO 2009b; European Commission 2012). Because, different geographical regions will be impacted differently by climate change, each country will need to prepare for and adapt to their changing local climatic conditions to protect health.

Direct adverse impacts are related to heatwaves, flooding and other extreme weather events (Pall et al. 2011), and these have received the most attention to date (García-Herrera et al. 2010). However, many impacts of climate change on human health will be indirect, i.e. not linked directly to weather events (Kurane 2009). In the UK the main climate related health threats include: summer heatwaves and droughts; flooding and its associated mental health issues (Paranjothy et al. 2011); interactions between air pollutants, pollen and higher temperatures (Cecchi et al. 2010; Laaidi et al. 2011); deterioration in food and water quality (Lobell et al. 2011); increase in vector borne diseases (Jones et al. 2008). Different UK regions will experience these impacts to different extents will be required to adapt locally to the new conditions.

The county of Cornwall (SW England, UK) has a maritime climate and will experience significant changes in weather patterns over the coming decades and it is predicted that by 2050-2080 the local climate will be 2 to 3 °C warmer than now, both in winter and summer (IPCC 2007). Cornwall will also experience longer periods of warm/hot and dry weather in spring and summer (CCRA 2012). Overall levels of precipitation will be similar to now, but more concentrated in the winter months (CCRA 2012). In addition it is predicted that extreme weather events will become more frequent, including heatwaves, storms, heavy rainfall, and cold spells (IPCC 2012). These changes will occur over the medium term, and are within the time frame of planning and development.

Due to the increase in temperatures, it is also likely that individual's exposure to UV radiation will also increase and therefore the risk of developing skin cancer. The south west of England currently experiences the highest incidence of both malignant and non-malignant melanoma in the UK (South West Health Observatory 2013). Although there are no specific figures for Cornwall, given its draw as a holiday destination, exposure it's likely to be high. A key outcome from the literature is the increased and continued risk of skin cancer in south west. This is highlighted by a series of public health campaigns to deliver messages regarding individual risk of exposure to UV, particularly in the summer months. The complex interactions between cloud cover, ozone depletion and higher UV levels is difficult to project but some studies/reports tentatively suggested summer UV irradiance will increase in the southern parts of the UK to approximately 12 Wm-2 and/or a slight increase in current UV flux, up to 10% by the end of the century (Hames & Vardoulakis 2012). Understanding how these climate-induced effects on health maybe influenced by socioeconomic dimensions is also considered but adds further complexity to using predictive methods. For example, melanoma is currently increasing at a rate of 5% per annum in the UK (Hames & Vardoulakis 2012), but this is largely attributed to individual changes in behaviour such as increased foreign travel and use of sunbeds. A study based on findings from mice and suggested that, "carcinoma was 5.5% higher for every 1oC increment in average temperatures, and basal cell carcinoma was 2.9% more common with every 1% increase. These values correspond to an increase in effective UV dose of 2% for each 1oC (van der Leun 2008; IPCC 2013)".

**Table 6.19-1: Summary of calculations for estimates of 'Total absolute excess of NMSC and MSC cases in 2050 due to impact of UV associated with climate change**

| **Non-melanoma skin cancer @ 3% increase per 1 deg C rise in mean temp** | | **Non-melanoma skin cancer @ 6% increase per 1 deg C rise in mean temp** | | **Malignant melanoma @ 3% increase per 1 deg C rise in mean temp** | | **Malignant melanoma @ 6% increase per 1 deg C rise in mean temp** | |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| 2010 population | 532300 | 2010 population | 532300 | 2010 population | 532300 | 2010 population | 532300 |
| 2010 incident cases of NMSC | 1922 | 2010 incident cases of NMSC | 1922 | 2010 incident cases of NMSC | 184 | 2010 incident cases of NMSC | 184 |
| Crude rate 2010 per 100k pop | 361.0746 | Crude rate 2010 per 100k pop | 361.0746 | Crude rate 2010 per 100k pop | 34.56697 | Crude rate 2010 per 100k pop | 34.56697 |
| | | | | | | | |
| Estimated crude rate in 2050 = 3% per deg = 7.5% increase in crude rate with a rise of 2.5 deg | 388.1552 | Estimated crude rate in 2050 = 6% per deg = 15% increase in crude rate with a rise of 2.5 deg | 415.2358 | Estimated crude rate in 2050 = 3% per deg = 7.5% increase in crude rate with a rise of 2.5 deg | 37.1595 | Estimated crude rate in 2050 = 6% per deg = 15% increase in crude rate with a rise of 2.5 deg | 39.75202 |
| | | | | | | | |
| Population 2050 | 665596.9 | Population 2050 | 665596.9 | Population 2050 | 665596.9 | Population 2050 | 665596.9 |
| Estimated total cases per year in 2050 with pop increase and effects of UV due to climate change | 2583.549 | Estimated total cases per year in 2050 with pop increase and effects of UV due to climate change | 2763.796 | Estimated total cases per year in 2050 with pop increase and effects of UV due to climate change | 247.3325 | Estimated total cases per year in 2050 with pop increase and effects of UV due to climate change | 264.5882 |
| Estimated crude rate of NMSC in 2050 with no climate change (=rate in 2010) | 361.0746 | Estimated crude rate of NMSC in 2050 with no climate change (=rate in 2010) | 361.0746 | Estimated crude rate of NMSC in 2050 with no climate change (=rate in 2010) | 34.56697 | Estimated crude rate of NMSC in 2050 with no climate change (=rate in 2010) | 34.56697 |
| Total cases per year in 2050 with pop increase only - if no effects of UV due to climate change | 2403.301 | Total cases per year in 2050 with pop increase only - if no effects of UV due to climate change | 2403.301 | Total cases per year in 2050 with pop increase only - if no effects of UV due to climate change | 230.0767 | Total cases per year in 2050 with pop increase only - if no effects of UV due to climate change | 230.0767 |
| | | | | | | | |
| Total absolute excess of NMSC cases in 2050 due to impact of UV associated with CC | 180.2476 | Total absolute excess of NMSC cases in 2050 due to impact of UV associated with CC | 360.4952 | Total absolute excess of MSC cases in 2050 due to impact of UV associated with CC | 17.25575 | Total absolute excess of MSC cases in 2050 due to impact of UV associated with CC | 34.51151 |

Note: 3% and 6% increase in skin cancer per 1°C temperature increase.

*Scenarios used:*

This analysis utilises the Shared Socioeconomic Pathways (SSP) 1 to calculate changes in GP list size in Cornwall to 2050. Given the complexities of accurate projections of UV, we utilised the IPCC's (2012) approximation of non-melanoma and melanoma increase per 1°C increase in temperature (see Table 6.19-3).

**Which adaptation tipping points can be identified?**

No adaptation tipping points can be identified in this case study as it is a 'no regrets' option.

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

**What are the alternative adaptation measures?**

Table 6.19-2 and Figure 6.19-1 give an overview of the major factors involved in driving skin cancer rates and for some potential adaptation options. Significant among these are options including:

Public health campaigns

- Urban planning and design in terms of shade availability and albedo of the ground
- Treatments; and
- Warning systems to raise awareness

In terms of the timing of adaptation for health impacts, it may be possible to adapt and apply the "adaptation pathways" model of Haasnoot (2012, 2013). This model identifies "tipping points" for adaptation, and in the health context major tipping points can be seen as being linked to the timing of damages:

- Primary interventions – before damage occurs to minimise exposure (e.g. a number of public health interventions)
- Secondary interventions – aim to prevent disease before it becomes manifest (e.g. screening tests)
- Tertiary interventions – applied once impacts occur (i.e. treatment regimes)

The development of new drugs or treatment regimes may also lead to the potential for a tipping point – e.g. the development of a new vaccine against a particular climate related condition. Factors that change the cost-effectiveness of given interventions may also be important – for instance through changes in the costs of raw materials or in the costs of production. Such factors may have a lagged impact – as they may take significant time to pass through government decision-making (e.g. review by NICE, the National Institute for Clinical Excellence, in the UK).

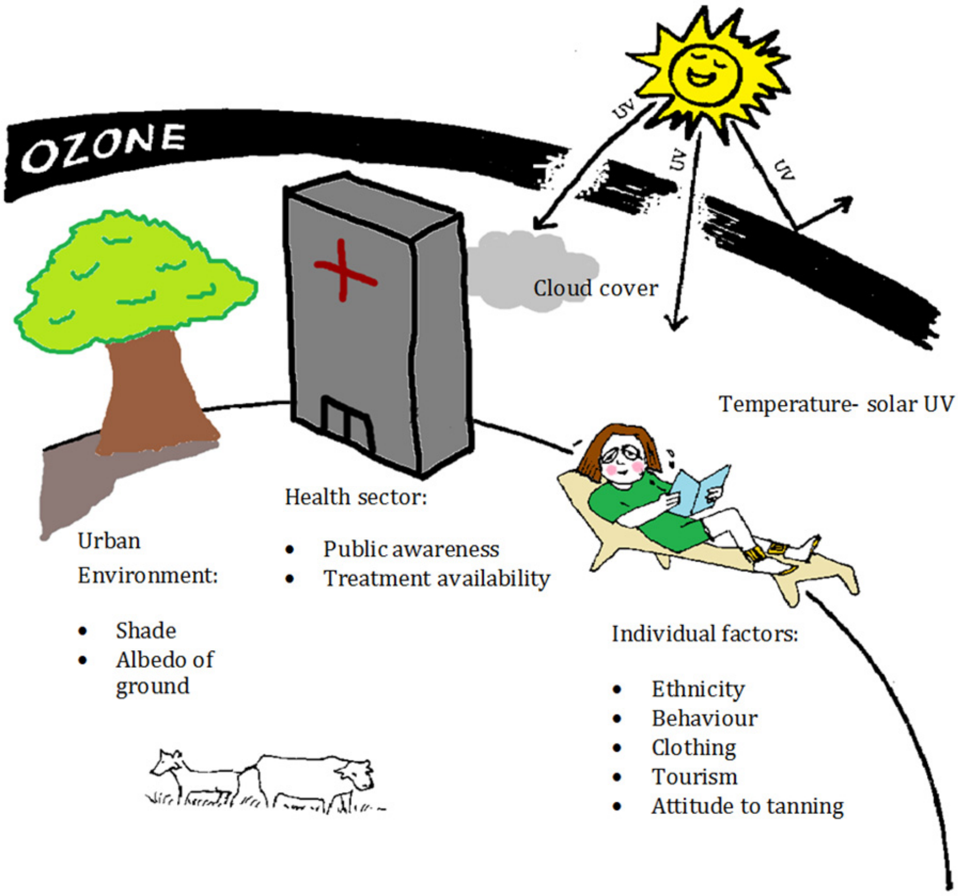


**Figure 6.19-1: Factors determining skin cancer incidence and possible adaptations**

Here, we consider the costs of the SunSmart programme. The SunSmart scheme cost £500k in England in 2010. Adjusting for population in Cornwall, this implies a cost of just under £5k for the Cornish case. The SunSmart programme involves a range of actions to increase awareness of the risks of skin cancer and sun exposure.

**Table 6.19-2: Overview of these interventions for skin cancer**

| Health Impact | Primary | Secondary | Tertiary |
|---|---|---|---|
| Skin cancer | Educational campaigns<br>Urban design: shading, altering albedo of the ground | Disease surveillance and monitory | UV warning system.<br>Skin cancer treatments |

**Step 3 – Evaluation Criteria and Method**

**Step 3a Selection of Evaluation Criteria**

**Which evaluation criteria should be used?**

We estimate the costs and benefits of the SunSmart scheme, considering the impacts on numbers of cases of skin cancer. We do not have a clear idea of the effectiveness of the programme, so we present the results for two scenarios: a 1 in 100 reduction in the number of skin cancer cases and an 8 in 10 reduction. The latter case is taken as 4 in 5 cases of skin cancer are thought to be avoidable – so this gives an upper bound.

We are not able to quantify the impact on the environment – nor the impacts of diverting resources to other demands in the National Health Service.

**Step 3b Selection of Evaluation Methods**

**What is the appropriate evaluation method?**

We use cost-benefit analysis, as it is possible to assess all cost and benefit criteria in monetary terms.

**Step 4 Data collection**

**What are the costs and what are the benefits of the alternative adaptation options?**

Taking the estimates of 3 to 6% increase for skin cancer and socioeconomic scenarios for population change, we can estimate the future cases in Cornwall as shown below.

To value these impacts in monetary terms, the Climate Change Risk Assessment took a central value of £2,425 per case of skin cancer based on a review of the literature. Valuing the impacts of melanoma and non-melanoma skin cancer using the same monetary value implicitly assumes the impacts are the same. Vallejo-Torres et al (2014) present an estimate of the cost of skin cancer in England in 2008, finding an average treatment cost per case of malignant melanoma of £4239 and of NMSC of £888. Taking these estimates and adding to the estimates for the welfare losses of a case of skin cancer based on the estimate used in the CCRA of £700 gives costs as follows (adjusted for inflation):

- Malignant melanoma - £5826 per case
- Non-melanoma skin cancer - £1874 per case

Note that these are likely underestimating the true cost of skin cancer – as we are valuing the welfare impacts using values from a study that has valued skin cancer in a generic way. Using these values, we can estimate the costs of skin cancer in Cornwall at £4.7 m (€5.5 m) in 2010. Under RCP4.5 and SSP1, these costs will increase to between £6.4 to £6.7 m (€7.5 to 7.8 m) by 2050.

**Table 6.19-3: Costs of skin cancer in Cornwall in 2010 and 2050**

| | 2010 | 2050 |
|---|---|---|
| Non Melanoma Skin Cancer 3% per 1C rise | £3,602,230 | £4,842,111 |
| Malignant melanoma 3% per 1C rise | £1,071,995 | £1,541,507 |
| **Total** | **£4,674,225** | **£6,383,618** |
| Non Melanoma Skin Cancer 6% per 1C rise | £3,602,230 | £5,179,932 |
| Malignant melanoma 6% per 1C rise | £1,071,995 | £1,541,507 |
| **Total** | **£4,674,225** | **£6,721,440** |

Note: SSP1, No discounting.

**What is the evaluation time frame?**

Annual

**Which discount rate should be applied?**

The UK government recommends a declining discount rate for climate change relevant projects. Here because the campaign is likely an annually renewing scheme, we compare costs and benefits for different years, rather than aggregating to one NPV.

**How to deal with data uncertainty?**

Where possible we will identify uncertainties and use appropriate methodologies to assess the impact of these.

**Step 5 - Selection of Evaluation Methods**

**What is the ranking order of alternative adaptation options (measures, bundles of measures or pathways)?**

We estimate the benefit/cost ratio in 2010 and 2050. The results are as shown in Table 6.19-4. It can be seen that the benefits far outweigh the costs, even if only 1 in 100 cases are avoided – and that with climate change and population growth the benefits will become even greater. It can also be seen that this is a “no regrets” option – i.e. it should be applied whether climate change occurs or not. Indeed, the climate impact is relatively small – of the total cases between 7 and 13% are attributable to climate change). It can be seen that the benefits far outweigh the costs, even if only 1 in 100 cases are avoided – and that with climate change and population growth the benefits will become even greater. It can also be seen that this is a “no regrets” option – i.e. it should be applied whether climate change occurs or not. Indeed, the climate impact is relatively small – of the total cases between 7 and 13% are attributable to climate change).

**Table 6.19-4: Benefit Cost ratio for SunSmart in Cornwall**

| B/C ratio | 2010 | 2050 |
|---|---|---|
| **1% reduction in cases** | | |
| 3% per 1C | 9.4 | 12.8 |
| 6% per 1C | 9.4 | 13.5 |
| **Max benefit (4 in 5 preventable)** | | |
| 3% per 1C | 751.7 | 1026.6 |
| 6% per 1C | 751.7 | 1080.9 |

## What are the main lessons learnt from your case study?

**Transferable results?**

The results from this study have downscaled findings at a regional scale and utilised existing data for south-west England specific skin cancer incidences. Cost benefit analysis at a local level largely mirrors findings at a regional scale, that the costs of running public health campaigns is outweighed by the benefits of reduced skin cancer incidence in Cornwall.

**Lessons learnt with regard to the process of economic valuation?**

**Feasibility of methods?**

The main lessons learnt relate to the complex nature of modelling UV data and the uncertainty of other climate data, ozone depletion and other environmental and individual behavioural complexities that are likely to interact and make predictions about the rates of skin cancer difficult. This is of particular importance in Cornwall as it is a prime holiday destination and records of diagnosed skin cancers may occur outside of the county.

**Important data sources**

We drew on findings from Cancer Research and data on skin cancer for South West held with the South West Health Observatory. Due to the complex nature of projecting UV in the future we also utilised information in the IPCC (2012) and personal communication with Public Health England.

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## 6.20 Leeds

Olivia Rendon, University Leeds

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

**What is the climate change related problem/risk you would like to reduce by adaptation?**

The history of flooding for the Aire Catchment and the Leeds area dates all the way back to 1616, and the most recent flood peaks occurred in autumn 2000, June 2007 and January 2008. Flooding has been found to be the main threat of climate change for Leeds and the River Aire catchment in the future. There are two related problems to be tackled with climate change, surface and fluvial or riverine flooding.

Analysis of the National Flood and Coastal Defence Database (NFCDD) in 2010 showed that the standard of protection within the Aire catchment, including Leeds, varies considerably, but the majority of it has very low protection (Aire Plan).

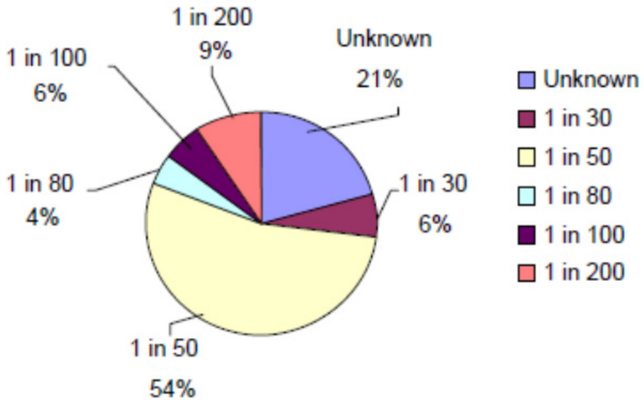


**Figure 6.20-1: Standard of protection within the Aire catchment**
Source: Aire Plan

**Table 6.20-1: Climate change projected for the Humber and Yorkshire region**

| | | Change Factors | | |
|---|---|---|---|---|
| **Change Variable** | **Uncertainty Range** | **Upto 2025** | **2025-2055** | **Beyond 2055** |
| **Precipitation % Winter** | Upper enhanced estimate | | | |
| | Upper end estimate | 8.1% | 16.4% | 46.5% |
| | Central estimate | 4.7% | 11.9% | 16.0% |
| | Lower end estimate | 1.6% | 7.8% | 1.7% |
| **Precipitation % Summer** | Upper enhanced estimate | | | |
| | Upper end estimate | -2.4% | -13.2% | -1.4% |
| | Central estimate | -8.8% | -20.2% | -24.8% |
| | Lower end estimate | -14.9% | -26.9% | -38.8% |
| **Precipitation % on Wettest Day - Winter** | Upper enhanced estimate | | | |
| | Upper end estimate | 8.2% | 16.3% | 43.9% |
| | Central estimate | 4.6% | 11.9% | 16.8% |
| | Lower end estimate | 1.2% | 7.7% | 0.5% |
| **Precipitation % on Wettest Day - Summer** | Upper enhanced estimate | | | |
| | Upper end estimate | 6.4% | 2.9% | 16.0% |
| | Central estimate | -0.3% | -4.0% | -5.1% |
| | Lower end estimate | -6.6% | -10.5% | -17.6% |
| **Peak River Flow %** | Upper enhanced estimate | 35.0% | 45.0% | 75.0% |
| | Upper end estimate | 25.0% | 30.0% | 50.0% |
| | Central estimate | 10.0% | 15.0% | 20.0% |
| | Lower end estimate | -5.0% | 0.0% | 5.0% |

Source: UKCP09

**Which assets and sectors are at risk under current climate variability?**

The following tables present a summary of the assets and sectors currently at risk of flooding in the Aire catchment and Leeds district, respectively, as reported in 2010.

**Table 6.20-2: Summary of all assets and sectors at current fluvial flood risk in the Aire catchment**

| Sector /Asset | Flood Risk | | | | |
|---|---|---|---|---|---|
| | 5% | 1.30% | 1% | 0.50% | 0.10% |
| **Physical** | | | | | |
| Catchment Area (km2) | 87.6 | 101.26 | 106.34 | 112.71 | 124.77 |
| Urban area (km2) based on ALC | 15.74 | 17.33 | 18.28 | 18.91 | 20.37 |
| Grade 1-3b agricultural land (km2) | 66.9 | 76.3 | 78.6 | 84 | 92.88 |
| **Social** | | | | | |
| Population | 17929 | 20923 | 22379 | 24019 | 28090 |
| **Infrastructure** | | | | | |
| Residential properties | 7795 | 9097 | 9730 | 10443 | 12213 |
| Commercial properties | 3056 | 3345 | 3647 | 3776 | 4112 |
| *Total properties* | 10851 | 12442 | 13377 | 14219 | 16325 |
| **Transport** | | | | | |
| Main roads (km) | 37.7 | 41.79 | 44.2 | 47.63 | 54.1 |
| Railway (km) | 34.58 | 40.05 | 42.15 | 46.51 | 51.8 |
| **Community** | | | | | |
| Hospitals, surgeries and health centres | 9 | 10 | 11 | 13 | 15 |
| Fire, ambulance and police stations | 2 | 3 | 3 | 4 | 4 |
| nurseries, schools, colleges and universities | 9 | 10 | 10 | 10 | 14 |
| **Tourism** | | | | | |
| camping and caravan sites | 2 | 2 | 2 | 2 | 2 |
| **Energy** | | | | | |
| gas and electricity assets | 140 | 161 | 172 | 183 | 201 |
| **Waste Sites** | | | | | |
| landfill sites | 1 | 1 | 1 | 1 | 1 |
| CoMAH sites | 1 | 1 | 1 | 1 | 1 |
| sewage treatment works | 3 | 4 | 4 | 4 | 6 |
| **Environmental** | | | | | |
| SAC km2 | 0.77 | 0.81 | 0.83 | 0.84 | 0.87 |
| SPA km2 | 0.01 | 0.01 | 0.01 | 0.01 | 1 |
| Ramsar sites | 0.53 | 0.56 | 0.57 | 0.57 | 0.57 |
| SSSI km2 | 2.46 | 2.57 | 2.6 | 2.63 | 2.72 |
| **Historical** | | | | | |
| WHS | 1 | 1 | 1 | 1 | 1 |
| Schedules ancient monument | 1 | 3 | 3 | 3 | 3 |
| Registered parks and gardens | 0 | 0 | 0 | 0 | 0 |
| Registered battlefields | 0 | 0 | 0 | 0 | 0 |
| Listed buildings | 347 | 355 | 404 | 410 | 455 |

Notes: SAC = Special area of Conservation; SPA = Special Protection Area; SSSI = Sites of Special Scientific Interest; and WHS = World Heritage Site
Source: Aire Plan (2010)

**Table 6.20-3: Summary of all assets and sectors at current fluvial flood risk in the Leeds District**

| Sector/Asset | 5% | 1.30% | 1% | 0.50% | 0.10% |
|---|---|---|---|---|---|
| **Social** | | | | | |
| Population | 5465 | 6014 | 6330 | 6962 | 7590 |
| **Properties** | | | | | |
| Residential | 2376 | 2614 | 2752 | 3027 | 3300 |
| Commercial | 1745 | 1863 | 1972 | 2123 | 2299 |
| *Total properties* | 4121 | 4477 | 4724 | 5150 | 5599 |
| **Transport** | | | | | |
| Main roads (km) | 14.29 | 15.66 | 16.21 | 18.12 | 19.27 |
| Railway (km) | 6.07 | 6.66 | 7.06 | 7.53 | 8.39 |
| **Community** | | | | | |
| Fire, ambulance and police stations | 1 | 2 | 2 | 2 | 2 |
| Nurseries, schools, colleges and universities | 1 | 1 | 1 | 1 | 1 |
| **Energy** | | | | | |
| Gas and electricity assets | 83 | 92 | 98 | 110 | 118 |
| **Waste Sites** | | | | | |
| CoMAH sites (top tier) | 1 | 1 | 1 | 1 | 1 |
| **Environmental** | | | | | |
| SSSI km2 | 0.01 | 0.02 | 0.02 | 0.03 | 0.03 |
| **Historical** | | | | | |
| Listed buildings | 153 | 165 | 178 | 182 | 190 |

Notes: SAC = Special area of Conservation; SPA = Special Protection Area; SSSI = Sites of Special Scientific Interest; and WHS = World Heritage Site
Source: Aire Plan (2010)

**Which adaptation or protection measures are already in place?**

*Non-structural:* awareness raising, disaster response management, monitoring and management, and land use planning (i.e. risk zoning). These measures, particularly disaster response by emergency services are deemed to be quite good. Note: before the currently implementing Flood Alleviation Scheme of grey infrastructure (started 2014), few isolated structural measures were in place.

*Structural:* improving flood defences (engineering; i.e. current implementation of grey infrastructure), improving flood defences (building with nature; some wetlands and flood plains exist but effectiveness is low or inexistent), giving space to rivers (the current grey infrastructure scheme which will remove the “Knostrop cut” island), improving drainage (Yorkshire Water is likely to regularly perform some drainage improvements but no official information is available), improving water retention (peak flows; see “building with nature” above), and flood resilient infrastructure (currently implementing weirs, walls and raised banks for the grey infrastructure scheme).

**How do these risks presumably change due to climate and socio-economic change?**

The following tables**Fehler! Verweisquelle konnte nicht gefunden werden.** show a summary of the assets and sectors at future flood risk in the Aire catchment and the Leeds district, respectively, as reported in 2010. The main assets affected by future flood risk are properties, transport and community assets.

**Table 6.20-4: Summary of % increase of all assets and sectors at future risk of fluvial flood in the Aire catchment**

| Sector /Asset | % increase of flood risk/ AEP | | | |
|---|---|---|---|---|
| | 5% | 1.30% | 1% | 0.50% |
| **Physical** | | | | |
| Catchment Area (km2) | 18.3 | 12.6 | 6.7 | 8.1 |
| Urban area (km2) based on ALC | 11.8 | 6.4 | 1.4 | 5.9 |
| Grade 1-3b agricultural land (km2) | 15.1 | 12.0 | 9.0 | 8.3 |
| **Social** | | | | |
| Population | 13.5 | 8.4 | 6.7 | 4.9 |
| **Infrastructure** | | | | |
| Residential properties | 13.5 | 8.4 | 6.7 | 4.9 |
| Commercial properties | 7.9 | 7.3 | 0.2 | 2.3 |
| *Total properties* | 21.4 | 15.7 | 6.9 | 7.2 |
| **Transport** | | | | |
| Main roads (km) | 12.5 | 9.5 | 6.3 | 9.0 |
| Railway (km) | 19.1 | 12.7 | 9.5 | 7.4 |
| **Community** | | | | |
| Hospitals, surgeries and health centres | 11.1 | 10.0 | 0.0 | 7.7 |
| Fire, ambulance and police stations | 50.0 | 33.3 | 33.3 | 0.0 |
| nurseries, schools, colleges and universities | 0.0 | 10.0 | 10.0 | 10.0 |
| **Tourism** | | | | |
| camping and caravan sites | 0 | 0 | 0 | 0 |
| **Energy** | | | | |
| gas and electricity assets | 12.9 | 5.6 | 4.7 | 9.3 |
| **Waste Sites** | | | | |
| landfill sites | 0.0 | 0.0 | 0.0 | 0.0 |
| CoMAH sites | 0.0 | 0.0 | 0.0 | 0.0 |
| sewage treatment works | 33.3 | 25.0 | 25.0 | 25.0 |
| **Environmental** | | | | |
| SAC km2 | 2.6 | 0.0 | 0.0 | 2.4 |
| SPA km2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Ramsar sites | 1.9 | 0.0 | 0.0 | 0.0 |
| SSSI km2 | 4.1 | 0.4 | 0.0 | 3.4 |
| **Historical** | | | | |
| WHS | 0 | 0 | 0 | 0 |
| schedules ancient monument | 200 | 0 | 0 | 0 |
| listed buildings | 11.2 | 14.9 | 3.0 | 8.3 |

Notes: CoMAH= Control of Major Accident Hazards, SAC = Special area of Conservation, SPA = Special Protection Area, SSSI = Sites of Special Scientific Interest, and WHS = World Heritage Site
Source: Aire Plan (2010)

**Table 6.20-5: Summary of % increase of all assets and sectors at future risk of fluvial flood in the Leeds District**

| Sector/ Asset | % increase of flood risk/ AEP | | | |
|---|---|---|---|---|
| | **5%** | **1.30%** | **1%** | **0.50%** |
| **Social** | | | | |
| Population | 6 | 6 | 9 | -1 |
| **Properties** | | | | |
| Residential | 6 | 6 | 9 | -1 |
| Commercial | 5 | 6 | 7 | -1 |
| *Total properties* | 6 | 6 | 8 | -1 |
| **Transport** | | | | |
| Main roads (km) | 20 | 3 | 5 | 4 |
| Railway (km) | 9 | 5 | 2 | 9 |
| **Community** | | | | |
| Fire, ambulance and police stations | 100 | 0 | 0 | 0 |
| nurseries, schools, colleges and universities | 0 | 0 | 0 | 0 |
| **Energy** | | | | |
| gas and electricity assets | 8 | 7 | 5 | 6 |
| **Waste Sites** | | | | |
| CoMAH sites (top tier) | 0 | 0 | 0 | 0 |
| **Environmental** | | | | |
| SSSI km2 | 100 | 0 | 0 | 0 |
| **Historical** | | | | |
| listed buildings | 10 | 6 | 2 | 2 |

Notes: CoMAH= Control of Major Accident Hazards, SAC = Special area of Conservation, SPA = Special Protection Area, SSSI = Sites of Special Scientific Interest, and WHS = World Heritage Site
Source: Aire Plan (2010)

**What are the main drivers, impacts and affected?**

The sectors are “flood risk management”, with the impact of flooding from increase in river flows, and “urban human settlements and infrastructure” (or production systems and physical infrastructures), with the impact of peak rainfall events. [I am not sure I understand what drivers the question refers to, but the drivers for increased flood risk are climate change, urbanisation, and population and economic growth.]

**Which climate and socio-economic scenarios are used?**

The UK Climate Projections (UKCP09) provide present three different future scenarios representing High (SRES A1FI), Medium (SRES A1B) and Low (SRES B1) greenhouse gas emissions. The UKCP09 central estimate of climate change for the Leeds area is used for the case study. The UKCP09 central estimate gives projections of peak river flow increase of up to 10% by 2025, 15% from 2025 - 2055 and 20% beyond 2055 (assuming rural and urban land use change will be effectively managed at a local scale to ensure no significant increase in flood risk). The socioeconomic scenarios used for the Leeds case study are those of the SSP2 and SSP5 storylines.

**Which adaptation tipping points can be identified?**

The adaptation pathways methodology was not applied in the Leeds case study, so the following statements are based on the adaptation measures’ lifetime, effectiveness and projected climate change. A key tipping point for Leeds will be around the year 2050 under both scenarios when climate change increases flood risk in most areas, e.g. 1 in 200 years becomes 1 in 75 years event. Another key tipping point is by 2100 due to population growth/urbanisation, particularly for SSP5.

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

**What are the alternative adaptation measures?**

*What are the primary and secondary objectives of adaptation?*

The case study aims to develop and evaluate three adaptation strategies for managing urban flood risk in the Leeds city region and Aire catchment. The primary aim of the adaptation measures is to reduce flood risk, and the secondary aim is to provide co-benefits.

*What are potential measures to meet these objectives?*

The potential measures for flood risk management include non-structural and structural.

The non-structural measures that already exist are awareness raising, disaster response management, monitoring and management, and land use planning (i.e. risk zoning). These existing measures, particularly disaster response by emergency services, are deemed to be working well. Economic incentives and risk transfer tools are two other non-structural measures that currently don't exist in Leeds and so far are not planned.

The structural measures for flood risk management that exist or have recently commenced (2014) in Leeds are improving flood defences (engineering) or flood resilient infrastructure, giving space to rivers (some in current grey infrastructure scheme), and improving drainage (by Yorkshire Water). However, giving space to rivers, improving water retention, and improving drainage, are measures that have limited or non-existent application.

**What is your baseline option (the "business-as-usual"-option)?**

The baseline option refers to current flood risk with existing non-structural adaptation measures without the grey infrastructure that is currently being implemented. Thus, impacts of current flood risk are being compiled and estimated for the Aire catchment and the Leeds district at an Annual Exceedance Probability (AEP) of 5%, 1.3%, 1%, and 0.5% (and in some instance at 0.1%).

*What is the ambition level of this baseline strategy?*

The ambition level is to maintain current risk levels but assuming that with climate change this risk will rise.

*Is current backlog of investments for adaptation measures included or excluded?*

The current secured investment of almost £50 m for the grey infrastructure in Leeds city centre is excluded from the baseline but included in the CBA of grey infrastructure for the whole of the Leeds District.

*Does it include only planned adaptation or also autonomous, non-planned adaptation?*

The baseline only includes planned adaptation.

*Are there complementary measures? Is it appropriate to bundle these measures?*

The non-structural measures are necessary alongside a combination of structural measures. The three adaptation measures explored in the Leeds case study need to be bundled for maximum flood risk reduction.

**What are alternative adaptation pathways?**

*What is the "sell-by"-date of the measures or bundles of measures?*

*Grey infrastructure* schemes for the Leeds district aim to achieve a 1 in 200 year protection but by 2050 this protection will decrease to 1 in 75 years due to climate change. *SuDS* and *EBA* will also decrease to an undefined level of protection.

*What would be alternative measures or bundles of measures at these "tipping points"?*

At the grey infrastructure "tipping point" in year 2050 is when the green measures of SuDS and EBA are alternatives to increase and enhance flood protection.

**Step 3 - Evaluation Criteria and Method**

**Step 3a Selection of evaluation criteria**

**Which evaluation criteria should be used?**

**Table 6.20-6: Evaluation criteria**

| Criteria | Grey infrastructure | SuDS | EBA |
|---|---|---|---|
| Costs | Appraisal, design, construction, risk, compensation, maintenance, estates | Capital and maintenance (low, medium, high) | Planting, tree shelters, gates, fencing, weeding, maintenance, woodland plan, scrub clearing, Rhododendron control, re-stocking health issue, thinning, labour, respacing |
| Excluded Costs | None | Design, risk | Design, risk |
| Benefits | Avoided damages to properties and vehicles, disruptions to rail and traffic | Water quality improvement, air quality improvement, energy savings, water savings, consumptive and non-consumptive recreation, ecology/biodiversity, aesthetics, surface and groundwater supply, carbon sequestration, climate cooling (health), avoided damages | Erosion reduction, runoff reduction, air quality improvement, recreation, aesthetics, carbon sequestration, biodiversity, timber, avoided damages |
| Excluded Benefits | Job creation, economic development | Reduced sound transfer, reduced heat island effect, job creation, economic development, health related (exercise opportunity, stress relief) and the above benefits were not available for all SuDS measures included | Improved water quality, job creation, economic development, health-related (exercise opportunity, stress relief) |

**What is the appropriate unit to measure each of these criteria? Is the performance of the adaptation options measured in qualitative, monetary or other quantitative terms?**

All included costs and benefits were monetised and those excluded were due to lack of data or inability to monetise.

**Step 3b Selection of evaluation method(s)**

**What is the appropriate evaluation method?**

The MCA or PCBA methods might have been used to include criteria not easily expressed in monetary terms, however due to time and resource constraints a cost-benefit analysis (CBA) approach was used.

**Step 3c Weighting of evaluation criteria**

**What are the preferences of stakeholders regarding the different evaluation criteria?**

The evaluation criteria are based solely on secondary data availability in documents such as those generated by local authorities, national authorities, scientists and practitioners. Stakeholders were not included in the criteria selection for the three CBAs, but there is evidence that they were included in the design of the grey infrastructure scheme being implemented; this scheme only considers traditional costs and benefits, excluding social and environmental costs and benefits.

**Step 4 - Data collection**

**What are the costs and what are the benefits of the alternative adaptation options?**

*What potential data sources are available, including damage & impact assessment methods or existing CBA studies on adaptation measures?*

*Grey infrastructure* cost and benefit data came from the Aire Catchment Flood Management Plan (2010), flood risk assessments for Leeds (2008, 2011), Local Climate Impacts Profile for Leeds (2009), Leeds city centre Flood Alleviation Scheme Project Appraisal Reports (2010, 2013), West Garforth Integrated Urban Drainage (2008), documents towards the development of the Wyke Beck flood alleviation scheme (2008 - 2010), among others.

*SuDS* cost data came from consultancy and NGO documents on SuDS costs and benefits (CIRIA 2013; Eftec 2010; HR Wallingford 2004; UKWIR Ltd. 2005), government documents (e.g. Environment Agency 2007), local data (e.g. Yorkshire Water 2014), among others. Benefits data is based directly or indirectly on the following documents: Environment Agency (2007), Roebuck et al. (2011), Royal Haskonings (2012), Sustrans (2010) and Woodland Trust (2011).

*EBA* cost data was based on the recent Woodland Capital Grants 2015 of the UK government and Forestry Commission documents. Benefit data is based mainly, directly or indirectly, on the following documents: CJC Consulting (2014), Defra (2011), Eftec (2010), Smith et al. (2012), Valatin and Starling (2010), and Woodland Trust (2015).

*If no relevant data sources are available and modelling cannot be undertaken: Which experts can estimate proxies for assessing the performance of measures regarding the respective criterion?*

Some benefits for the SuDS and the EBA approaches are not available and could be estimated via proxies by SuDS engineer experts, public health professionals and environmental economists.

*How do the adaptation options perform with regard to each of the cost and benefit criteria selected in step 3a?*

The following table shows that only the grey infrastructure and the EBA adaptation options are cost-effective. The SuDS technology (based on UK figures) seems to be prohibitively expensive at a large scale.

**Table 6.20-7: Efficiency of adaptation options grey infrastructure, SuDS, EBA**

| Criteria/ Discount rate | Grey Infrastructure | SuDS (20% coverage & high benefits) | EBA |
|---|---|---|---|
| **PV Costs** | | | |
| 1% | £ 271,863,504 | £ 639,653,880,883 | £ 715,074,908 |
| 3.5% | £ 337,647,984 | £ 2,013,861,981,797 | £ 2,328,564,777 |
| 5% | £ 525,892,385 | £ 12,932,971,606,314 | £ 13,730,165,938 |
| **PV Benefits** | | | |
| 1% | £ 5,262,645,065 | £ 60,025,693,027 | £ 20,493,116,283 |
| 3.5% | £ 13,555,471,871 | £ 177,211,459,014 | £ 72,209,214,640 |
| 5% | £ 83,950,062,874 | £ 955,372,732,478 | £ 494,072,859,908 |
| **NPV** | | | |
| 1% | £ 4,990,781,561 | - £ 579,628,187,856 | £ 19,778,041,375 |
| 3.5% | £ 13,217,823,887 | - £ 1,836,650,522,783 | £ 69,880,649,863 |
| 5% | £ 83,424,170,489 | - £ 11,977,598,873,836 | £ 480,342,693,970 |
| **BCR** | | | |
| 1% | 19.36 | 0.09 | 28.66 |
| 3.5% | 40.15 | 0.09 | 31.01 |
| 5% | 159.63 | 0.07 | 35.98 |

**What is the evaluation time frame?**

*What is the lifespan of the measure with the longest lifetime?*

The timescale is 100 years from the end of 2014 to 2114 following the lifetime of the current grey infrastructure scheme.

**Which discount rate should be applied?**

*Which discount rate is recommended by national guidelines for climate change adaptation measures (or public investments)? Is it a linear discount rate or any other type (i.e. declining, hyperbolic, etc.)*

The following declining discount rate is recommended by the UK government (HM Treasury 2011):

| **Period of Years** | 0 - 30 | 31 - 75 | 76 - 125 |
|---|---|---|---|
| **Discount Rate** | 3.5% | 3% | 2.5% |

And a low (1%) and high (5%) discount rates were applied for testing the sensitivity of results.

**How to deal with data uncertainty?**

The *grey infrastructure* measure is based on hydrological modelling (considering other alternatives also) and estimations by consultancies with expertise in the area. The measure itself is also quite straightforward and it takes account for risk in its estimates, thus it is considered to have low uncertainty.

The *SuDS* measure estimates' consider 1%, 5% and 20% coverage in the Leeds district as well as low and high benefit values, which provide some insight into uncertainty.

The *EBA* measure, besides discount rate, does not include any range of criteria. However, the SuDS and EBA measures are based on conservative estimates to avoid overestimations.

**Step 5 – Evaluation and Prioritization**

**What is the ranking order of alternative adaptation options (measures, bundles of measures or pathways)?**

*For cost-benefit analysis: What is the net-present value of the alternative options?*

**Table 6.20-8: Net present value of adaptation options grey infrastructure, SuDS, EBA**

| Criteria/ Discount rate | Grey Infrastructure | SuDS (20% coverage & high benefits) | EBA |
|---|---|---|---|
| **NPV** | | | |
| 1% | £ 4,990,781,561 | - £ 579,628,187,856 | £ 19,778,041,375 |
| 3.5% | £ 13,217,823,887 | - £ 1,836,650,522,783 | £ 69,880,649,863 |
| 5% | £ 83,424,170,489 | - £ 11,977,598,873,836 | £ 480,342,693,970 |

*What is the benefit-cost ratio?*

**Table 6.20-9: Benefit-cost ratio of adaptation options grey infrastructure, SuDS, EBA**

| Criteria/ Discount rate | Grey Infrastructure | SuDS (20% coverage & high benefits) | EBA |
|---|---|---|---|
| **BCR** | | | |
| 1% | 19.36 | 0.09 | 28.66 |
| 3.5% | 40.15 | 0.09 | 31.01 |
| 5% | 159.63 | 0.07 | 35.98 |

*What are the uncertainties associated with the performance of the different options?*

There is little uncertainty in the performance of the *grey infrastructure*. There is large uncertainty in the performance of the *SuDS* and *EBA* approaches as they are based on green measures, the literature offers wide ranging performance values and are context specific. Hydrological modelling could help reduce uncertainty in the latter two approaches although not completely.

*Is there and, if so, to what extent uncertainty in the ranking of options?*

There is uncertainty in the cost-effective ranking of the options, mainly due to the inability to monetise several benefits of the SuDS approach and some of the EBA approach.

*Is it possible to determine which option most likely performs best or is it necessary to gather further information to reduce uncertainty?*

As designed, the best performing alternative is the grey infrastructure with a protection up to 1 in 200 years.

## What are the main lessons learnt from your case study?

There is a substantial amount of cost and benefit data available in government and consultancy work for the UK (grey literature; main source of data) which is quite disperse and at times hard to access (e.g. Defra and Environment Agency documents).

The early involvement of key stakeholders in the economic evaluation process would have likely facilitated access to data.

It is still not possible to capture all the direct and indirect benefits of the “green” adaptation measures, which probably has a strong influence on the cost-effectiveness of measures (i.e. SuDS).

The application of cost-benefit analysis to three different adaptation measures for Leeds and the Aire catchment provides important insights into areas that need further attention and research (e.g. quantification of benefits derived from SuDS), and the general feasibility of the measures.

The exploration of different socioeconomic scenarios and the impacts of climate change highlight periods in time when tipping points might occur and how different adaptation measures might be combined and/ or staggered to distribute costs in time and provide the necessary standard of protection.

The findings support the need to consider a bundle of adaptation measures beyond traditional approaches, and a wider catchment focus, in order to achieve a high standard of protection as well as multiple benefits.

## 6.21 South Devon

Roos M. den Uyl and Duncan Russel, University of Exeter

### Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points

#### What is the climate change related problem/risk you would like to reduce by adaptation?

The South Devon Coast, located in the South West of England, is an important area for tourism; it includes two small towns, and it includes some sites with heritage and nature conservation. In addition, it includes some important infrastructure connecting the South West of England to larger cities such as London. This study focuses at the coastal area stretching from the town of Teignmouth (at the relative southwest), including the town of Dawlish, through Dawlish Warren (at the relative northwest); covering a length of about 10km. Provision of housing/residential areas, infrastructure and tourism, and heritage and nature conservation are already under pressure from coastal erosion and sea and river flooding, a situation which will be exacerbated by climate change.

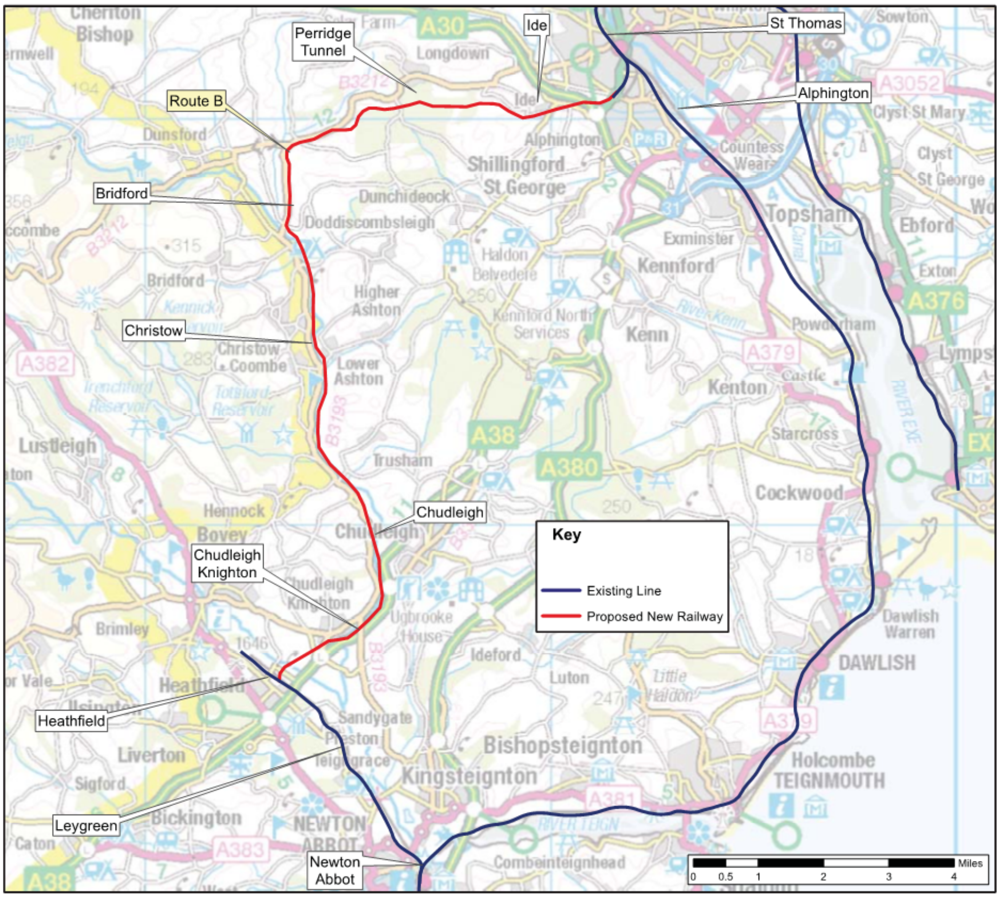


**Figure 6.21-1: Existing railway and cheapest proposed alternative route**
Source: Network Rail 2014

The recent extreme events at the coast at Dawlish (February 2014), which severely damaged the sea wall and the railway, increased the risk of flooding for the houses behind the sea wall, and disconnected the railway connection of the southwest of England to the rest of the country, demonstrate these pressures. The railway is on a wave cut platform sandwiched between sandstone cliff and the sea. Moreover, due to the geomorphological setting of rocky/cliff shores at the South Devon coast, options for managed flood plains, or for example dikes, or managed realignment of the coast are limited which presents further challenges when considering and developing climate change adaptation pathways. The railway infrastructure and associated sea wall are particularly vulnerable to sea storm events and slumping of the cliffs due to undermining by waves and excess rainfall, which soaks into the cliffs undermining the structural integrity of the rock. Climate change adaptation at the Dawlish coast has been topic of discussion. As adaptation it is a very complex issue at this location, several groups have formally and informally attempted to outline the main issues and several options. But a formal adaptation strategy has so far been absent. In general, after the recent extreme events at the Dawlish coast, we can diagnose that – as far as there have adaptation actions – these have been clearly insufficient to prevent severe disruptions such as severe flood risks and infrastructure disconnections. Projected increases in sea level rise from UKCIP (2009) even under low emissions scenarios suggest that minimum sea level rise could be 40cm under a low emissions scenario and up to 58.9cm under a high emissions scenario by 2080 (see Table 6.21-1), significantly increasing the risk of waves topping and damaging the railway line flood defences during storm events in the future. Dawson (2012, p176) calculates that was for every historical 0.05m rise in sea level, line restrictions (reduced service or line closure) increased by on average 7%. As it is difficult to provide good estimate of future storm surge activities this data is used to understand the risks faced by the railway line, but does not include full risks as the soft sandstone cliff is also at risk of slumping when it has been exposed to a lot of rainfall. Data on the future risks of this are not possible to obtain.

**Table 6.21-1: Predicted sea level rise from 1990 levels or the Dawlish coast based on UK CIP data**

| Year | Sea-level rise low emissions (cm) | Sea-level rise medium emissions (cm) | Sea-level rise high emissions (cm) |
|---|---|---|---|
| 2020 | 4.7 | 5.7 | 6.8 |
| 2040 | 15.1 | 18.3 | 22.0 |
| 2060 | 26.8 | 32.6 | 39.3 |
| 2080 | 40 | 48.6 | 58.9 |

Source: Dawson (2012)

**Fluvial flooding risk to property**


!

**Figure 6.21-2: Map of Dawlish Water**

**Figure 6.21-3: Picture of Dawlish Water**

Dawlish water is a small river that runs through the centre of Dawlish. It has a small catchment (2400ha) from the hill behind which is mainly covered by farm and woodland. It is flanked by a thin strip of parkland, which is in turn surrounded by commercial and residential property. Our field works suggests there are about 50 properties at risk from 1 in 30 year flood events. Data from UKCIP (2009) suggests that this risk is likely to increase to 1 in 24 by 2020, 1 in 18 by 2060 (see Table 6.21-2). In the most recent flooding in this area in 2012, 5 properties suffered flood damage on their ground floors.

**Table 6.21-2: Increases in the risk of extreme flooding events at Dawlish water for a low and medium emissions scenario (UKCIP)**

| Time Period | Flood risk |
|---|---|
| Now-2020 | 1/30 |
| 2020-2040 | 1/24 |
| 2040-2060 | 1/24 |
| 2060 -2080 | 1/18 |

*Scenarios used:*

**This analysis uses data from UKCIP09 (2009) projections. These comprise of the** fifth generation of climate change information for the UK, and are based on a methodology designed by the Met Office. The Projections are presented for three different future scenarios representing high (equivalent to SRES A1FI of the IPCC Special Report on Emissions Scenarios and RCP 8.5 of BASE), medium (equivalent to SRES A1B) and low (equivalent to SRES B1; RCP 4.5 of BASE) greenhouse gas emissions (UKCP09 website). For this analysis, the medium range is used with the high and low end scenarios forming the basis of the uncertainty analysis.

**Which adaptation tipping points can be identified?**

Key tipping points are related to increases in sea level and storm events in relation to the Dawlish Railway and increase in extreme run off events in relation to Dawlish Water. However our analysis which runs from the present until 2080, does not suggest a tipping point will be reached. Data on climate impacts are associated with 20 year time periods in line with UK CIP (2009) projections, namely the present-2020, 2020-2040, 2040-2060, and 2060-2080. After 2080, analysis from Dawson (2012) suggests that the viability of the Dawlish coastal section of the railway, may well depend on the vulnerability of its estuarine routes prior at either end of the exposed coastal section (the Exe and Teign Estuaries respectively), which would be vulnerable to minimum predicted sea-level rises of 54.5 cm by 2100 and maximum rises of up 80.6cm under a high emissions scenario (Dawson 2012).

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

**What are the alternative adaptation measures?**

*Dawlish Railway line*

Objective – to make the South West of England's railway infrastructure and related economic benefits less vulnerable to storm events at the Dawlish coast.

There were three main options compared:

1. Business-as-usual. This option entails maintaining the existing sea defences at Dawlish and conducting repairs to damage to the rail infrastructure, cliffs and sea wall from storm events as and when they occur.
2. Strengthen the existing sea defences. This would involve strengthening and heightening the sea wall, stabilising the cliffs through wire netting and bolting, and measures to mitigate the erosion of beech material (e.g. improved groynes).
3. Reroute the railway inland away from the Dawlish coast. There are several proposed options for doing this, the cheapest of which is using the old Teign Valley line (Network Rail 2014) (see Figure 6.21-1).

*Dawlish Water*

Objective: to reduce the risk of flooding to properties bordering Dawlish Water

So the three options for this analysis are:

1. Business as usual

This entails no intervention to protect the 50 at risk properties. Flooding happens periodically and affected properties are cleaned up.

2. The installation of domestic flood gates at 50 at risk properties


**Figure 6.21-4: Example of a domestic floodgate**

Individual domestic floodgates to be fitted to all 50 properties (Figure 6.21-4).

3. The installation of sluice gates up stream to hold back flood water, thus protecting property in the two centre. In extreme events tis may not be enough to hold back all of the flood water and thus protect all properties.

In the analysis it is assumed that both options reduced risks by 100%. Sensitivity analysis is conducted around different risk scenarios for the two options.

**Step 3 - Evaluation Criteria and Method**

**Step 3a Selection of evaluation criteria**

**Which evaluation criteria should be used?**

*Dawlish Railway line*

Direct costs: maintenance and repair costs of the sea wall and the railway infrastructure, statutory compensation to train operators and passengers for interrupted services, the building of new infrastructure in the form of a new inland railway, the upgrading of existing infrastructure (heightened sea defences etc.);

Direct benefits: Avoided damages to the sea wall and rail infrastructure, avoided maintenance to the sea wall and rail infrastructure, avoided statutory compensation to train operators and passengers for travel interruptions.

Indirect benefits: Avoided wider economic disruption to the region, avoided costs of interruptions to freight transport, and avoided costs of interruption to business, commuter and leisure passengers.

*Dawlish Water*

Direct costs: capital costs of flood prevention measures (Sluice gate and domestic property floodgates), costs of clearing up flood damage to properties.

Direct Benefits: Avoided costs associated with flood damage to properties.

All costs and benefits can be expressed in monetary values, in this case £ Sterling.

**Step 3b Selection of evaluation method(s)**

**What is the appropriate evaluation method?**

Yes, past studies and a recent report by network rail and other government agencies have allowed us to collect data on monetary costs and costs and benefits. Most of the benefits valuations come in the form of avoided damages. So a cost-benefit analysis is conducted. For Dawlish water, it would also have been suitable to conduct a cost-effectiveness analysis. However, this would not have included details on avoided flood costs, which provide a compelling case on the need for action. Thus a CBA was conducted. All calculations were conducted in £ sterling and converted to EUR at the average 2014 rate of €1.2404 per £1.[91]

**Step 4 - Data collection**

**What are the costs and what are the benefits of the alternative adaptation options?**

Data has been collected form a variety of sources including a PhD thesis (Dawson 2012), reports from Network Rail, reports form the UK Environment Agency, the UK Climate Impacts Programme (UKCIP, 2009)

*Dawlish Rail*

Research by Dawson (2012) was used to gather many of the base line monetary data surround the likely impact and costs of climate change on the Dawlish railway line. Through modelling historical line closes in relation to line closes Dawson (2012, p176) was able show that for every historical 0.05m rise in sea level, average line restrictions (reduced service or line closure) increased by on average 7%. He then used this data to model future line disruptions and closure based on different UKCIP (2009) sea-level rise scenarios, namely low, medium and high. For the purpose of this analysis we use the mid-range estimates, with the impacts of the lower and higher ranges on costs being incorporated into the Monet Carlo simulation.

[91] Calculated using: http://www.oanda.com/currency/average

*Direct costs*

The UK National Audit office suggests that the standard delay minute costs for each train lies at around £73.47 per minute. These charges are used to compensate train operators and passengers.

Dawson's modelling (2012, p.198) of the Dawlish railway also found that frequency of delays are proportional to the frequency of maintenance and repair. Therefore an approximate cost of maintenance and damage repair was calculated by multiplying the average annual maintenance costs buy the annual % change in delay minutes. According to Network Rail (2014), current maintenance costs are approximately £0.8 m per year, above that of maintenance costs of a normal railway line, with a further £5 m spent on average every five years to repair a severe damage after a major event. As a point of reference the damage form the 2014 storm cost over £20 m in repairs. This means that annual expenditure is approximately £1.8 m a year.

**Table 6.21-3: Projected sea level rise at Dawlish and associated increases in line delays and closures**

| Year | Sea-level rise | Average minutes with line restrictions and closures/yr. |
|---|---|---|
| **Low emission scenarios** | | |
| 2015-20 | 3.0 | 3,900 |
| 2020-40 | 4.7 | 6,510 |
| 2040-60 | 15.1 | 12,326 |
| 2060-80 | 26.8 | 18,836 |
| **Medium Emission scenarios** | | |
| 2015-20 | 3.0 | 3,900 |
| 2020-40 | 5.7 | 7,049 |
| 2040-60 | 18.3 | 14,098 |
| 2060-80 | 32.6 | 22,110 |
| **High Emission Scenarios** | | |
| 2015-20 | 3.0 | 3,900 |
| 2020-40 | 6.8 | 16,178 |
| 2040-60 | 22.0 | 25,847 |
| 2060-80 | 39.3 | 36,825 |

Source: UK CIP (2009), Dawson (2012)

*Indirect costs*

Drawing on information from The Department of Transport, Dawson (2012) estimates (adjusted for inflation using the UK Treasury's GDP deflator) that value of working time per rail passenger is £45.91 per hour, non-working value time for a commuter is £6.18 per hour and for all other passengers is £5.47 per hour. Using data obtained from the train operating company, First Great Western, Dawson also calculates the annual number of business journeys on the line to be approximately 296,788, commuter journeys to be around 2,065642 and other journeys in the region of 1,594,739. With this data it is possible to estimate an average daily cost in terms of lost passenger time from line restrictions or closure. In terms of freight costs, there are approximately 12 trains a day. Based on research by Clarke et al (2010), delay costs of fright trains costs about £46 per train for a 30-60 minute delay and £1674 for a 12-14 hour delay.

In a recent report on the viability of the Dawlish line, the rail operator estimated that upgrading the existing line, to make it less vulnerable to storm events through cliff stabilisation and raising the height and strengthening of the defences could cost between £398-659 m (including a 60% contingency). It should be noted that this estimate also covers work on the estuarine routes the line takes entering and leaving the coastal section of the railway. The costs of this work would be spread over a 20-year period meaning that the full effects of the work would not be realized for 20 years. As network rail did indicate the effectiveness of these measures in terms of risk reduction, calculations were based on a 50% reduction in damage scenario and unlikely 100% damage reduction scenario. As the work would be completed over a 20-year period, the 50% risk reduction damage was phased in cumulatively over that period.

The Network Rail report (2014) also outlined different alternative railway routes and the costs. We calculated the costs and benefits of the cheapest of these options (see Figure 6.21-1) the Teign Valley route at a capital building cost of £470 including a (60%) contingency. The work would be completed by 2027. Up until this time the existing Dawlish route would be used with associated maintenance and storm damage costs. Following this, these costs would be turned into benefits in terms of costs avoided. It is noted that that there are costs to the Dawlish line closure that we have not been able to include in these calculations, such as continued sea wall maintenance to protect the Town of Dawlish. These costs would be significantly lower than current costs as a major piece of infrastructure (the railway) will not need to be protected. It has not been possible to ascertain figures for these costs. There may also be costs in terms of reduced tourism as the line is a major attraction to the area and it also delivers tourists to nearby resorts. However, a line may be able to be maintained that stops at the nearby resort of Dawlish warren before the railway runs parallel to the sea.

*Dawlish Water*

It is estimated by the UK environment agency that ground floor flooding of property costs on average £20,000-£30,000 to clear up. Flood protection gates for individual property can cost (including installation) anywhere between £500-£1000 depending on the size of the property. For this analysis 50 gates are assumed fitted at the mean average of £750 per gate, the uncertainty in the price was handled through a Monte Carlo simulation. In addition, a sluice gate can be added to Dawlish water to hold back floodwaters before they hit the urban area. The Local Authority has just commissioned the building of a gate at the cost of £10,000. As it cannot be certain ultimately how affective these measures will be for protecting the property the cost benefit was conducted under different scenarios in terms of number properties protected by the measure and number of properties directly in the path of the flood. The projected annual costs of flooding per was estimated by multiplying the number of houses at direct risk of flood damage (50) by the mean average cost of property flood clear up (25000), divided by the risk factor derived from UKCIP (2009).

**Table 6.21-4: Projected climate related increase in flood damage costs**

| Time Period | Flood risk | Annual cost of flood damage |
|---|---|---|
| Now-2020 | 1/30 | £20,833 |
| 2020-2040 | 1/24 | £26,042 |
| 2040-2060 | 1/24 | £26,042 |
| 2060 -2080 | 1/18 | £34,722 |

**What is the evaluation time frame?**

All of the measures are potentially viable and therefore explored over a similar life span from 2015-2080.

**Which discount rate should be applied?**

We will follow discounting guidelines outlined in the UK Treasury's Green Book on appraisal[92]. Thus a discount rate of 3.5% will be used. Sensitivity analysis will be conducted using a 1% and 5 % discount rate where appropriate.

**Step 5 – Evaluation and Prioritization**

**What is the ranking order of alternative adaptation options (measures, bundles of measures or pathways)?**

Where we had data ranges for monetary costs and benefits we based the analysis on average figures and then under took a Monte Carlo analysis to account for data uncertainty associated with lower and higher end range boundaries.

**Dawlish railway - Cost Benefit of the Options @ 3.5 discount rate, 2015-2080**

*Option 1: Business as usual*

[92] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/220541/green_book_complete.pdf

Costs of maintenance and repairs = £70,491,340

Fines and compensation for delays = £21,564,888

Indirect economy wide effects (passenger time and goods) = £48,661,451

PV total costs only = £140,717,679; €174,546,209

The rail connection from the region to London and the North of England, provides a vital and quick transportation route for the region (compared to other transportation options), which in terms of other transport links is a fairly geographically isolated part of the UK. The recent closure of the Dawlish line was claimed to have cost the regional economy £20 m a day. This is a very rough estimate from the regional chamber of commerce. If this figure were to be true and assuming these costs were not offset but road transport (which is unlikely as the region has little capacity for vastly improving road routes), this would mean economic benefits of maintaining a rail link would be in the region of £5,175,007,808 (discounted at 3.5%) for the time period of this analyses (2015-2080).

*Option 2: Strengthen the existing line (50% damage reduction)*

Capital of strengthening the works (50% damage reduction) = £381,824,989

Total maintenance costs =£54,352,226

Fines and compensation for delays = £13,070,810

Indirect delay costs (passenger time and goods transport) = £29,865,648

Total costs = £478,113,673

NPV (Benefits – costs)

Benefits (costs avoid from option 1) = £140, 717, 679

Benefits – costs = NPV £-337,395,994; €-418,505,991

At this level of NPV, even if the works provided 100% protection from line disruption, with total capital costs remaining at £381,824,989 and maintenance cost at £20,680,312 (this figure takes account of maintenance at 0.8 per year as in 2015), total costs are £402,505,301. Thus the NPV of benefits – costs is = £-261,787,622

*Option 3: Cheapest new inland rail route*

Cost of works= £322,680,145

Maintenance of existing coastal track until 2027 = £20,407,947

Delay fines on existing coastal track until 2027 = £4,750,398

Indirect costs of delays (passenger time and goods) = £5,838,697

Total costs = £353,677,182

NPV (Benefits – costs)

Benefits (costs avoid from option 1) = £140,717,679

Benefits – costs = NPV £-212,959,503; €-264,154,968

**Sensitivity analysis**

Adjusted figures to reflect a 1% discount rate mean that

PV option 1 (costs only) = £324,592,996; €402,625,152

NPV option 2 (benefits – costs): £ -346,711,065; €-430060405

NPV option 3 (benefits –costs) = £ -107,374,326; € -133,187,114

Adjusted figures for a 5% discount rate:

PV option 1 (costs only): £93,882,937; €116,452,395

NPV option 2 (benefits – costs): £ -289,947,473; €-359,650,846

NPV option 3 (benefits-costs): £- 201,962,015; €-250,513,683

**Data uncertainty: Monte Carlo analysis**

To account for uncertainty in the data (outlined above), a Monte Carlo Simulation was conducted for each of the options:

Option 1: Standard deviation = 7930480; mean = 182945623; standard error = 1,733508 or 0.94%

Option 2: Standard deviation = 77,999,124; mean = 585,893,442; standard error = 8,201,604 or 1.4%

Option 3: Standard deviation = 130,094,182; mean =429,951,213; Standard error = 5785933 or 1.35%

***Summary – Dawlish Rail***

**Table 6.21-5: Summary of Dawlish Rail analysis**

| Option | NPV @ 3.5% | Standard error |
|---|---|---|
| 1. Business as usual | PV £140,717,679 (costs only)<br>€174,546,209 | 0.94% |
| 2. Strengthen existing defences | NPV £-337,395,994 (benefits-costs)<br>€-418,505,991 | 1.40% |
| 3. New inland rail route | NPV £-212,959,503 (benefits –costs)<br>€-264,154,968 | 1.35% |

Given the importance of the rail link to the region, which could - if the regional chamber of commerce estimates that the recent railway closure cost the region £20 m a day are accurate - provide benefits (discounted at 3.5%) over the period of this analysis of £5,175,007,808. If this the case then here is a strong case for keeping the line open either in situ or through a new inland route. The cheapest of options for doing this, based on this analysis, is option one, business as usual. However, the line is also vulnerable to sea level rise in the along the estuaries it runs parallel to before and after leaving the coastal section (the Exe and Teign estuaries respectively) (see Figure 6.21-1). Dawson (2012) estimates that these estuarine sections of the railway may be non-viable by 2100 because of sea level rise, meaning that a new inland route will eventually have to be built regardless of what happens on the coastal section. If this new route (based upon option 3 prices) were built over a six-year period from 2090, the costs (@3.5 discount) would be £27,615,751 (€34,254,578) compared to £322,680,145 (€400,252,452) to build the new route for completion by 2027. Thus even under this scenario, option one seems the base approach for the studied time period (2015-2080).

*Dawlish Water*

Measures to minimize the risk of flood damage – sluice gate and domestic floodgates  - are relatively easy to complete with minimal maintenance costs. These can theoretically be installed in 2015.

**Table 6.21-6: Costs of anti-flood measures**

| | |
|---|---|
| **Domestic flood gates (option 2)** | £37,500 (installed in 50 properties at £750 per installation) |
| **Sluice gate (option 3)** | £10,000 |

**Table 5.5 Costs and Benefits of measures and actions**

| | **Total cost 2015-2080** | **NPV at 3.5% discount** |
|---|---|---|
| **Flood damage cost (50) at risk properties** | £1,947,917 | £1,077,100 |
| **Domestic flood gates (50 properties)** | £37,500 | £37,500 (installed in year 1) |
| **Sluice gate upstream of the town** | £10,000 | £10,000 (installed in year 1) |

**Cost benefit of the options @ 3.5% discount, 2015- 2080**

*Option 1: Business as usual*

No benefits identified.

Projected total flood damage cost: PV = £1,077,100; €1,336,035

*Option 2: Fitting of domestic flood gates to 50 properties*

Costs of measure = £37,500

Benefits (flood costs avoided) = £1,077,100

Benefits – costs NPV = £1,042,100; €1,292,621

*Option 3: Fitting a sluice gate upstream of Dawlish*

Costs of measure= £10,000

Benefits (flood costs avoided/e)  = £1,077,100

Benefits - costs NPV = £1,067,100; €1,323,631

The Sluice gate and the domestic floodgates would require some maintenance. We have not been able to ascertain costs for these, but estimate them not be to be high. They would need to be extremely high to significantly lower the benefit cost ratio.

**Sensitivity analysis**

*1% discount*

The analysis was repeated with a 1% discount rate.

Option 1 – business as usual. PV (flood costs) = £1,375,647; €1,706,353

Option 2 – installing 50 domestic flood gates, NPV (benefits – costs) = £1,340,647; €1662939

Option 3 – installing a sluice gate, NPV (benefits-costs) = £1,365,647; €1,693,949

*5% discount*

The analysis was repeated with a 5% discount rate.

Option 1 – business as usual. NPV (flood costs) = £805,112; € 998,661

Option 2 – installing 50 domestic flood gates, NPV (benefits – costs) = £770,112; € 955,247

Option 3 – installing a sluice gate, NPV (benefits-costs) = £795,112; €986,257

*Effectiveness of measures*

If only 50% are properly protected by the measure the cost benefit ratio becomes negative. An only 50% protection of at risk properties is more likely to happen in a community wide measure like the sluice gate, which are not targeted at individual properties, rather than a domestic measure like the individual property floodgates.

*No change flood risk from 2015 baseline of 1/30 @ 3.5% discount*

Option 1- Business as usual PV (costs only) = £416,269; €516,340

Option 2 – Domestic flood gates NPV (benefits – costs) = £381,269; €472,926

Option 3 - sluice gate NPV (benefits-costs) = £406,269; €503,936

***Data uncertainty: Monte Carlo analysis***

Option 1: Option 3: Standard Deviation = 14,594; mean = 139,894; standard error = 4,378 or 3.13%

Option 2: Standard Deviation = 17,493.56; mean = 174,772; standard error = 1,883 or 1.08%

Option 3: Standard Deviation = 14,594; mean = 139,894; standard error = 4,378 or 3.13%

***Summary – Dawlish Water***

**Table 6.21-7: Summary of Dawlish Water analysis**

| Option | (N)PV @3.5% discount | Standard Error |
|---|---|---|
| 1. Business as usual | £1,077,100 (costs only)<br>€1,336,035 | 3.13% |
| 2. 50 domestic flood gates | £1,042,100<br>€1,292,621 | 1.08% |
| 3. Sluice gate | £1,067,100;<br>€1,323,631 | 3.13% |

Based on this analysis, it would seem that the sluice gate (option 3) provides the best-cost benefit outcome. Individual floodgates also provide a positive NPV and probably give property owners greater assurance that their houses are protected as opposed to a community wide protections measures such as the sluice gate, which may not protect all properties in light of more extreme events.

## What are the main lessons learnt from your case study?

**Transferable results?**

I am not sure how transferable the results are especially for the Dawlish railway analysis, which is highly context specific because of the unique situation of the railway line. The analysis of domestic flood protection measures (domestic flood gates) vs. community flood protection measures (sluice gate on the river), may have wider transferability to flooding in other contexts as it is less unique.

**Lessons learnt with regard to the process of economic evaluation?**

I learnt a lot especially as it has been a long time since I have conducted a CBA. Three, things stand out: first the number of assumptions that are made which although based on sound reasoning may never materialise; how the boundaries of the analysis in terms of what measures and costs and benefits to include and not include may impact upon the final results; and three, how through looking a localised case you may miss out important information from the bigger picture – in this case that the Dawlish coast is not the only part of the rail line that is vulnerable and that these other vulnerabilities may provide the tipping point for rerouting.

**Feasibility of methods?**

The CBA seemed to be feasible but some information wasn't available and I didn't have the resources to collect primary data to fill these gaps. See also my points in the above answer on assumptions etc.

**Important data sources?**

The work of other academics, the UKCIP, Government Agencies and business provided the bulk of the data that was needed.

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## 6.22 Mental Health UK

Sahran Higgins, Tim Taylor, University of Exeter

**Step 1 – Preliminary Risk Assessment and identification of adaptation tipping points**

**What is the climate change related problem/risk you would like to reduce by adaptation?**

Climate change may have significant adverse impacts on human health (IPCC 2007). Consequently, increasing attention is now being given to the issue of adaptation (IPCC 2007; Stern 2007; Costello et al. 2011). The effects of anthropogenic climate change have been discernible for a number of years (WHO 2009a). Most people will have noticed changes to the weather (Kerr 2011) and in the timing of seasonal events such as earlier flowering (Fitter and Fitter 2002). Weather anomalies and extreme events are becoming more frequent globally (e.g. heat waves and flooding). Over the coming decades, societies will need to adapt to the changing climate (Stern 2007) based on local requirements.

England, UK has a maritime climate and will experience significant changes in weather patterns over the coming decades and it is predicted that by 2050-2080 the local climate will be 2 to 3 °C warmer than now, both in winter and summer (IPCC 2007). England will also experience longer periods of warm/hot and dry weather in spring and summer (CCRA 2012). Overall levels of precipitation will be similar to now, but more concentrated in the winter months (CCRA 2012). In addition it is predicted that extreme weather events will become more frequent, including heat waves, storms, heavy rainfall, and cold spells (IPCC 2012). These changes will occur over the medium term, and are within the time frame of planning and development.

Direct adverse impacts are related to heat waves, flooding and other extreme weather events (Pall et al. 2011), and these have received the most attention to date (García-Herrera et al. 2010). However, many impacts of climate change on human health will be indirect, i.e. not linked directly to weather events (Kurane 2009). In the UK the main climate related health threats include: summer heat waves and droughts; flooding and its associated mental health issues (Paranjothy et al. 2011); interactions between air pollutants, pollen and higher temperatures (Cecchi et al. 2010; Laaidi et al. 2011); deterioration in food and water quality (Lobell et al. 2011); increase in vector borne diseases (Jones et al. 2008). Different UK regions will experience these impacts to different extents will be required to adapt locally to the new conditions.

Climate change adaptation in terms of minimising or avoiding human health impacts is now taking centre stage (Kurane 2009; Bell 2011). Improvements in the resilience of healthcare systems to meet future climate change will save money long-term and will also assist in coping with natural catastrophes. The World Health Organization (WHO) and the European Commission are both funding research aimed at facilitating health adaptation to climate change (WHO 2009b; European Commission 2012). Because, different geographical regions will be impacted differently by climate change, each country will need to prepare for and adapt to their changing local climatic conditions to protect health. However, given the overwhelming recognition that climate change is likely to impact significantly on mental health, either via exacerbating existing conditions or through new depression diagnosis, there remains no explicit mental health and climate change adaptation plan. Given the immense pressure already faced by the National Health Service, adapting to changing mental health treatment demands and understanding possible climate-related triggers (e.g. temperature, rainfall), may become increasingly important under current climate change scenarios.

*Scenarios used:*

This analysis utilises the RCP 4.5 climate scenario with associated Shared Socioeconomic Pathways (SSP) 1 to calculate changes in GP list size to 2050. We have also used a GP-weighted Index of Multiple Deprivation (IMD), modified to include an estimate of a weighted average of the IMD scores for each LSOA (Lower Super Output Area) in which a given practice has registrations. The weights are the % of the practice's registrations in each LSOA (HSIC 2011). We were specifically interested in whether there was an association between mental health (depression and anxiety) and climate variability. Panel analysis (random effects, Table 6.22-1) of these data suggested that, as might be expected, cost of prescribing increases as precipitation, cloud cover and UV increase, but decreases with rising temperatures.

**Table 6.22-1: Panel data analysis (month within practice)**

| RCP4.5 - Cost per person | B | p | 95% CI | |
|---|---|---|---|---|
| % Cloud cover | 0.007076 | <0.001 | 0.0066 | 0.0076 |
| Cloud ^2 | -0.000048 | <0.001 | -5E-05 | -4E-05 |
| Precipitation (cm/day) | 0.000090 | <0.001 | 8E-05 | 1E-04 |
| Precip ^2 | 0.000000 | <0.001 | -3E-08 | -2E-08 |
| Mean temp (K) | -0.282623 | <0.001 | -0.291 | -0.2746 |
| Temp ^2 | 0.000493 | <0.001 | 0.0005 | 0.0005 |
| UV (J/m2/s) | 0.000788 | <0.001 | 0.0008 | 0.0008 |
| UV ^2 | -0.000002 | <0.001 | -2E-06 | -2E-06 |
| | | | | |
| Urban | ref | | | |
| Town/fringe | 0.045956 | <0.001 | 0.0369 | 0.0551 |
| Rural | 0.06356 | <0.001 | 0.0492 | 0.0779 |
| | | | | |
| IMD - Quintile 1 (least deprived) | ref | | | |
| Q2 | 0.025882 | <0.001 | 0.017 | 0.0347 |
| Q3 | 0.027652 | <0.001 | 0.0186 | 0.0367 |
| Q4 | 0.028639 | <0.001 | 0.0195 | 0.0378 |
| Q5 | 0.01475 | 0.002 | 0.0055 | 0.024 |
| | | | | |
| ICC | 0.76 | | | |

**Which adaptation tipping points can be identified?**

In this case the adaptation being considered is largely autonomous – so when temperature increases demand for prescriptions and mental health services will likely reduce in terms of mild to moderate depression.

**Step 2 – Identification of Adaptation Measure and Adaptation Pathways**

**What are the alternative adaptation measures?**

In terms of the timing of adaptation for health impacts, it may be possible to adapt and apply the "adaptation pathways" model of Haasnoot (2012, 2013). This model identifies "tipping points" for adaptation, and in the health context major tipping points can be seen as being linked to the timing of damages:

- Primary interventions – before damage occurs to minimise exposure (e.g. a number of public health interventions)
- Secondary interventions – aim to prevent disease before it becomes manifest (e.g. screening tests)
- Tertiary interventions – applied once impacts occur

Table 6.22-2 gives an overview of these interventions for different health impacts of climate change.

The development of new drugs or treatment regimes may also lead to the potential for a tipping point – e.g. the development of a new vaccine against a particular climate related condition. Factors that change the cost-effectiveness of given interventions may also be important – for instance through changes in the costs of raw materials or in the costs of production. Such factors may have a lagged impact – as they may take significant time to pass through government decision-making (e.g. review by NICE, the National Institute for Clinical Excellence, in the UK). Thus, the emergence of new anti-depressants may influence the findings here.

In the recent past, extreme weather events have increased awareness of climatic risks and assisted in driving policy in terms of the installation of heat warning systems.

**Table 6.22-2: Primary, Secondary and Tertiary Adaptation**

| Health impacts | Primary | Secondary | Tertiary |
|---|---|---|---|
| Heat stresses | Building and technical solutions.<br>Urban planning (green roofs, etc.).<br>Heat health warning systems (preventive).<br>Educational campaign. | | Heat health warning systems (reactive).<br>Emergency plans and medical services. |
| Extreme weather events related deaths, injuries, mental health effects | Structural measures to reduce flooding (dykes, walls)<br>Land-use and urban planning (flood-resistant).<br>Early warning systems and real-time forecasting. | Disease surveillance and monitoring | Emergency and evacuation plans.<br>Diagnosis and treatment |
| Water-borne diseases | Water and sanitation systems.<br>Information and health education. | Disease surveillance and monitoring. | Diagnosis and treatment (early detection). |

Source: BASE Deliverable 4.1

**Step 3 – Evaluation Criteria and Method**

**Step 3a Selection of Evaluation Criteria**

**Step 3b Selection of Evaluation Methods**

**What is the appropriate evaluation method?**

We are able to assess the benefits in terms of improved mental health, with reduced cases of mild to moderate depression, in terms of:

- Reduced prescription costs;
- Reduced losses of earnings;
- Reduced pain and suffering; and
- Reduced mortality risk due to suicide.

We are not able to quantify the impact on the environment – nor the impacts of diverting resources to other demands in the National Health Service.

**Step 4 Data collection**

**What are the costs and what are the benefits of the alternative adaptation options?**

Examples of previous literature that have valued depression include Hames and Vardoulakis (2012) who estimated the costs of a case of depression at £970 2010 prices based on Bower et al (2010). In this study they also assumed that 10% of those flooded developed depression.

Thomas and Morris assessed the costs of depression for the year 2000 in England (Thomas 2003: 355). They estimated NHS treatment costs for depression at £369,865,000 (2000 prices) and that there were just under 2.7 m cases of depression – implying an average cost of £138.97 per case (2000 prices). These were adjusted to bring to 2013 prices. Thomas and Morris also examined morbidity costs in terms of incapacity benefit and loss of earnings and the costs associated with mortality. The former is identified directly for the case of Ménière’s, and to count also the cost of depression would be to risk double counting. In terms of mortality, Thomas and Morris report 2615 deaths associated with depression, and use measures based around lost earnings to place a monetary value. Such a method to value premature mortality is controversial, and does not account for a number of other values. The UK government uses a "value of a prevented fatality" of £1.145 m (HMT, Green Book) based on measures of willingness to pay for mortality risk reduction and estimates of other costs including lost output. This compares to the £214,913 per fatality estimated by Thomas and Morris.

There are difficulties in applying valuation methods to QALY gains. For example, Van Houtven et al (2006) used meta-regression analysis of morbidity valuation studies and examines whether there is a relationship between willingness to pay and health status measures. They analyse 230 WTP estimates from 17 studies and find that QALY based estimates of illness severity are significant in explaining variation in willingness to pay, but they reject the assumption of a constant WTP per QALY gain. Gyrd-Hansen (2005) explores the theoretical and methodological issues relating to the identification of willingness to pay for a QALY, suggesting from a theoretical perspective one unique willingness to pay estimate cannot be found. Issues faced include diminishing marginal utility of health and differences in values of incremental health in different populations.

The initial stage of the analysis showed a growth in total cost of prescribing that was primarily driven by a) projected climate change and b) projected population growth (fig 1). We calculated the growth in prescribing costs due to population change alone by multiplying the baseline average cost per person by the projected monthly populations (i.e. what would the total cost be if cost per person stayed constant, but population grows?) We subtracted this from the results of the first set of projections to get the estimated monthly total cost due to climate changes alone, and this indicates that the average monthly difference was around -£750k (total) – i.e. projected prescribing costs were more if climate stayed the same as 2010, than if it changes as predicted (fig 2).

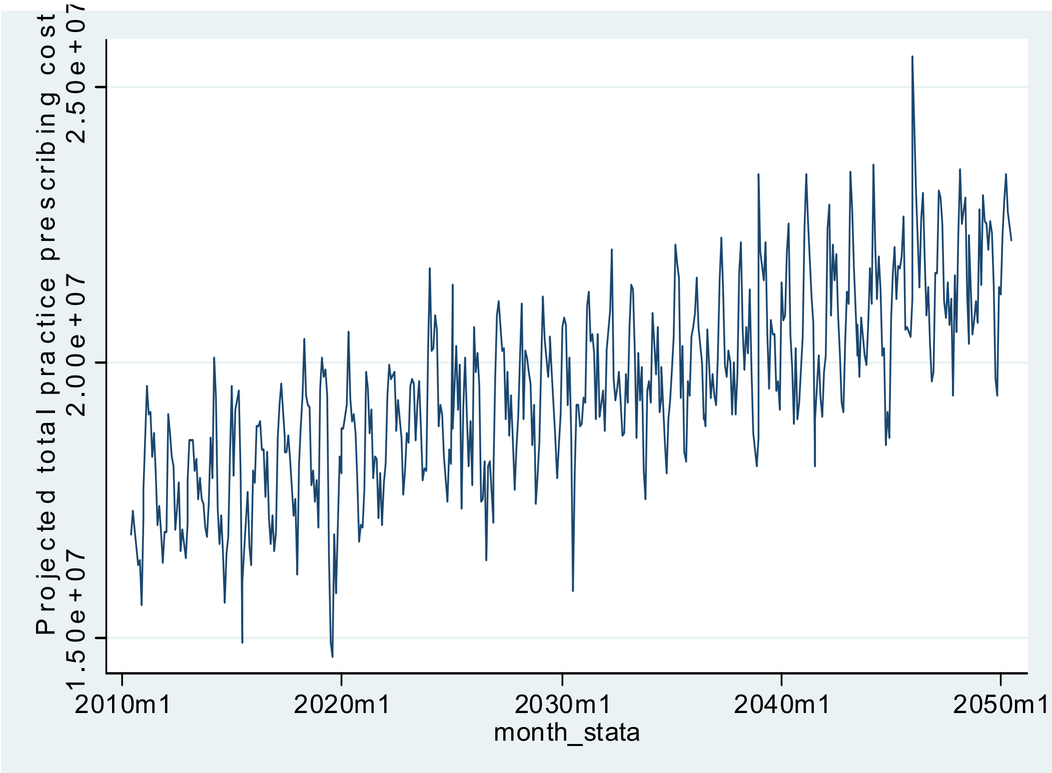


**Figure 6.22-1: Forecast costs of depression to 2050**

Notes: The model gives us the regression coefficients for antidepressant prescribing cost per person predicted by weather, IMD and urban/rural for months 2010-2012. These coefficients were then applied to monthly weather data to 2050 (and assume that the geography of deprivation and urbanisation remains constant until 2050) to give us a projected monthly cost per person. The national SSP population growth rate forecasts were applied to practice populations in 2010 to estimate monthly practice population to 2050. Projected cost per person was then multiplied by projected practice population for each month to give total cost of prescribing per practice per month. These were summed across all practices to give an estimate of total (England) monthly prescribing cost per month.

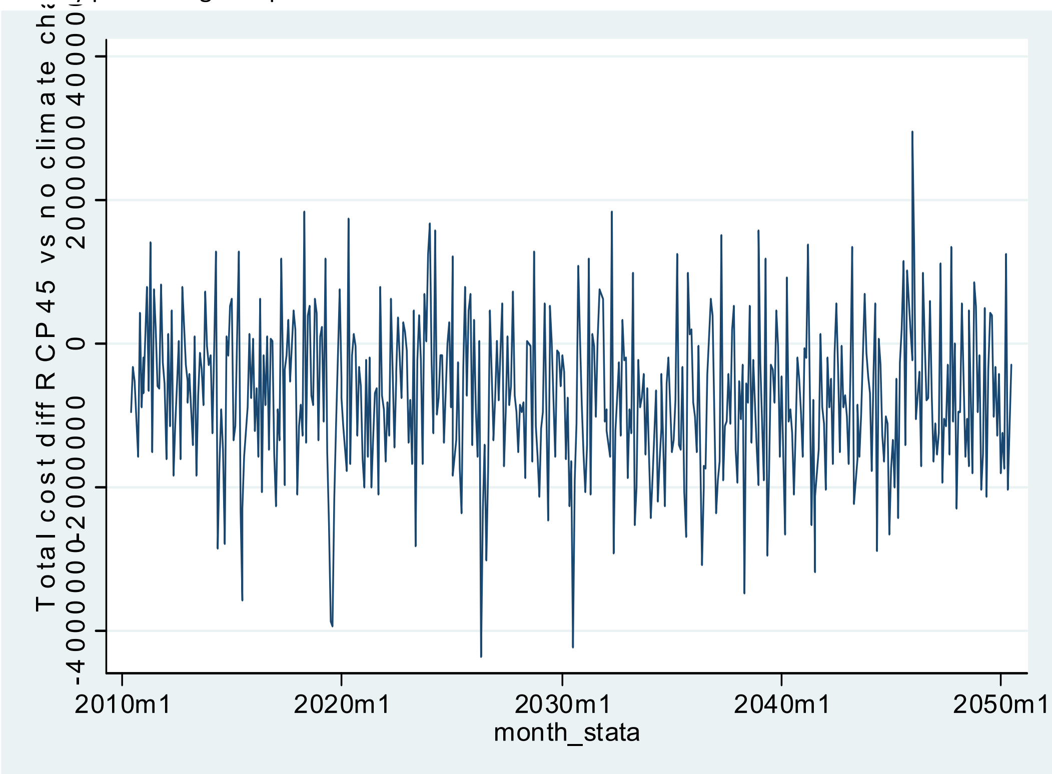


**Figure 6.22-2: Forecast costs of prescribing to 2050**
Note: RCP4.5 versus no change in climate

Shioroiwa et al (2010) use a double bounded dichotomous choice with bidding game to estimate willingness to pay for one additional quality adjusted life year gained in seven countries. They used an internet survey and found willingness to pay in the UK of £23,000, compared to $63,000 in the United States, AU$64,000 in Australia, JPY 5 m in Japan, KWN 68 m in Korea and NT$2.1 m for Taiwan. Bobinac et al (2010) also used contingent valuation to assess QALY gains in the Netherlands. They found mean WTP per QALY was €12,900 based on VAS (Visual Analog Scale) valuations and €24,500 based on the Dutch EuroQol tariffs. Income was a significant determinant of WTP, with those on high incomes willing to pay €75,400 and those on low incomes just €5,000. Pinto-Prades, Loomes and Brey (2009) examined the values of different health states in Spain using standard gambles to elicit utilities for two different health states, one representing moderate problems on some health dimensions of the EQ-5D instrument and the other representing moderate problems on most dimensions and severe on anxiety and depression. Willingness to pay was elicited using cards – with respondents identifying amounts they were willing to pay, those they were not willing to pay and others that they were uncertain about. They found that there was serious doubt over whether a reliable all-purpose monetary value of a QALY could be derived from a survey on quality of life, risk and duration. Problems included insufficient sensitivity to the duration of health states and size of quality of life improvements, as well as order effects, payment period effects and “chaining” effects.

Donaldson et al (2011) compared results for the WTP per QALY based on modelling results drawing on the Value of a Prevented Fatality and the results of a survey using discrete choice experiments. This study was largely focussed on the development of the methodology – and so a representative sample of the population was not used. The modelling results yielded a value of £10,000 to £70,000 per QALY, whereas the survey results suggested values of between £18,000 and £40,000 per QALY – though some results were implausibly high.

**Table 6.22-3: Selected studies on willingness to pay per QALY**

| Study | Location | Treatment type (group in brackets) | Elicitation method | WTP per QALY estimate |
|---|---|---|---|---|
| Cunningham and Hunt (2000) | UK | Orthognatic treatment (patients) | Standard gamble for health status and payment scale for WTP | £506 |
| Blumenschein and Johannesson (1998) | USA | Asthma (patients) | Rating scale, time trade-off and standard gamble for health status and dichotomous choice + bidding games for WTP | $7,000 to $46,000 |
| Zethraeus (1998) | Sweden | Hormone Replacement Therapy (patients) | Rating scale and time trade-off for health status, dichotomous choice for WTP | 118,400 SEK to 156,100 SEK |
| Bala et al (1998) | USA | Shingles (general population) | Standard gamble for health status and dichotomous choice for WTP | $15,588 to $49,133 depending on treatment |
| Olsen and Donaldson (1998) | Norway | Three health care programmes (general public) | Author estimates for QALY gains based on descriptions, payment card for WTP | 0.2 NOK to 6.7 NOK |
| Shioroiwa et al (2010) | Various: UK, USA, Australia, Japan, Korea and Taiwan | Generic serious illness (general public) | Dichotomous choice with bidding game | UK £23,000, USA $63,000 Australia AU$64,000 Japan JPY 5 m Korea KWN 68 m Taiwan NT$2.1 m |
| Bobinac et al (2010) | Netherlands | Two different health states (general public) | Visual analog scale and Euroqol for health status, contingent valuation for WTP based on payment scale + open ended | €12,900 to €24,500 |
| Donaldson et al (2011) | UK | Range of health states (unrepresentative sample of general public) | Standard gamble/person trade-off for health states ; Discrete choice experiment for valuation | £18,000-£40,000 (eliminating "implausibly high values") |
| Gyrd-Hansen (2003) | Denmark | Range of health states (general public) | Health states based on EQ-5D, Discrete choice experiment for valuation | DKK88,000 |
| Gyrd-Hansen and Kjaer (2012) | Denmark | Chronic inferior health state | Health states using EQ-5D and time trade off, WTP using dichotomous choice and payment card | DKK2,404 to DKK 241,963 |
| King et al (2005) | USA | Hypothetical treatment raising to full health | Health states using standard gamble, time trade-off and visual analog scale; WTP using iterative closed ended bidding | $12,500 to $32,200 |
| Byrne, O'Malley and Suarez-Almazor (2005) | USA | Osteoarthritis (general public) | Health states using visual analog, time trade-off and standard gamble, WTP based on open-ended | $1,221 to $5,690 |

Given the above, we value costs per QALY using the NICE threshold of £30,000 per QALY. The average weight attributable to mild to moderate depression is 0.125 – so multiplying through this gives a value of £3750 per patient year for reduced symptoms of mild to moderate depression. Taking these factors into consideration, we have calculated the additional, wider economic benefits of background climate change on mental health, given the apparent protective effects of climate change (driven by temperature) on mental health. These benefits associated with reduced symptoms of mental health conditions include: Productivity gains, reduced pain and suffering, reduced mortality (reduction in suicides). To do this, an estimated value is calculated by transforming the output from a cost measure to 'patient year equivalent'. This allows estimation of the costs of treatment, lost earnings, pain and suffering and mortality in the future – adjusting for socioeconomic change and changes in average temperatures leads to estimates of benefits as shown below.

**Table 6.22-4: Economic value of mental health benefits of changes in average climate in England: 2040-2045**

| Cost type | Value (£ m) | Value (m EUR) |
|---|---|---|
| Treatment costs | 12.7 | 15.7 |
| Lost earnings | 1,473.4 | 1817.4 |
| Pain and suffering | 1,391.30 | 1716.1 |
| Mortality | 551.4 | 680.1 |

Notes: RCP4.5, SSP1, 2012 prices, no discounting

**What is the evaluation time frame?**

The adaptation here is autonomous – admittedly it is subject to variation due to changes in prescribing behaviour. Recent trends towards other treatment types are noted, but demand for these types of therapies will also likely decline with climate change.

**Which discount rate should be applied?**

The UK government recommends a declining discount rate for climate change relevant projects. Here we do not have a project to assess, so no discounting is needed.

**How to deal with data uncertainty?**

Uncertainties exist in a range of areas. The values will be sensitive to assumptions on the values of health, notably the value of a Quality Adjusted Life Year and the Value of a Preventable Fatality. Reducing the value of a QALY to the lowest value of Donaldson et al (2011) changes the value of pain and suffering from £1.4 bn to £835 m

**Step 5 - Selection of Evaluation Methods**

**What is the ranking order of alternative adaptation options (measures, bundles of measures or pathways)?**

The adaptation here is largely autonomous, and we have shown that the benefits of mental health reductions are significant. There are a number of caveats with this analysis, however, including:

- The analysis relies on a rather limited data set;
- The assumption that "patient equivalent years" can be estimated from drug consumption; and
- The values attributable to health outcomes are subject to some uncertainty.

The results here would be robust to the climate scenarios under the BASE project, given the strong temperature signal.

## What are the main lessons learnt from your case study?

**Transferable results?**

The results are interesting as they suggest the possibility of a protective effect of climate variability on mental health (using prescribing as a proxy), which is largely mediated by an increase in temperature. Where these results are interesting, it is extremely likely that they are not transferable given the context-specific nature of a) impacts of climate change of regions and b) variability in mental health in these regions.

**Lessons learnt with regard to the process of economic valuation?**

The unexpected results meant we were unable to conduct a cost-benefit analysis due to the suggested impact of climate variability potentially improves mental health in the UK. This makes this case study particularly unusual.

**Feasibility of methods?**

The main lessons learnt relate to the complex nature of attempting to link climate variability data to health data. The complex nature of combining these kinds of data into a geography that is appropriate for comparative analysis is a long process. Understanding the complexities of prolonged exposure to background climate variability on mental health is key when comparing the impacts of severe weather impacts (e.g. storms, flooding, extreme heat and cold) to develop adaptation strategies going forward.

**Important data sources**

The health-related data (prescription, GPs) was obtained from NHS data sources, socioeconomic data from census-derived data (2011) and climate data from CORDEX.

BASE report

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