BASE BOTTOM-UP CLIMATE ADAPTATION STRATEGIES FOR EUROPE

Title: **Methodological framework for upscaling and integrating bottom-up approaches for European analysis and assessment of the impacts, costs and benefits of climate adaptation**

Summary: Whereas deliverables 6.1 and 4.1 have provided common guidelines for using scenarios, defining adaptation pathways and evaluating them on costs and benefits, this deliverable 6.2 describes the procedure how to upscale results from case study level to more generalized conclusions on costs and benefits at EU level. For water availability, agriculture, floods, ecosystem services, health and cities, therefore first a literature review of earlier attempts for upscaling of costs and benefits using either qualitative accumulation, meta-analysis or models is presented. Secondly a procedure for the case study execution and reporting and model validation is proposed that should ensure optimal use and connection of models and ground data within BASE.

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SEVENTH FRAMEWORK PROGRAMME

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Contents

BASE report

1 Introduction and aims of this document

Deliverable 6.2 reports the advancements of the work accomplished by WP6 under Tasks 6.2: Methodological framework for up-scaling and assessing the costs and benefits of climate change adaptation.

Task 6.2 develops a methodology for the up-scaling of the estimates of costs and benefits of adaptation produced in the case studies (WP4 and WP5).

In deliverable 6.1 upscaling was defined as an activity in which information on a lower spatial scale is translated into information at a higher spatial scale. This information on a lower spatial scale is scattered sparsely in space and often highly context specific. A certain representativity for a broader context or larger area of similar characteristics is required for scalability. In the context of BASE, and more specifically WP6, the information to be upscaled is gathered from the case studies and consists of adaptation pathways and its characteristics, costs of impacts and adaptation, and adaptation benefits. As an example; the benefits of a certain flood risk reduction action, studied in detail at the local scale for a specific catchment, can be translated by using the models developed and applied in BASE, to the European scale, for catchments where a similar measure is supposed to be relevant.

BASE will combine two sources of information for upscaling:

- Using case study clusters: groups of similar cases studies executed under WP5
- Using models

When using models BASE again adopts two approaches. The first approach develops adaptation modeling solutions to use the cost and benefit information and features of adaptation measures to assess the costs, effectiveness and impacts of adaptation measures in climate-proofing Europe's key sectors. Key parameters within the models are estimated, improved and validated based on ground data e.g. from BASE case studies. The second one seeks to generalize the evidence on costs and benefits of adaptation generated by local studies by using extended input-output modelling and other approaches, in order to generate estimates of wider economic impacts for member states and the European Union.

Task 6.2 will evaluate the case study results on costs and benefits and try to identify communalities that might be useful to compare with and to add to EU scale model results.

The work in the task will involve:

- reviewing up-scaling approaches for the economic costs and benefits of climate adaptation measures;
- developing a methodological framework for the up-scaling of impacts and economic results of case studies to member state and European levels;

- up-scaling data from bottom-up adaptation processes for analysis of costs and benefits at European scale;
- establishing a process tool for testing and evaluating future plans for climate adaptation.

Within deliverable 6.2 the first 2 bullet points will be dealt with. The last 2 bullet points will contribute to deliverable 6.3.

First of all, a review of existing upscaling studies for estimating costs and benefits will be given in chapter 2. Chapter 3 will further discuss the approaches for the up-scaling of impacts and economic results of case studies to member state and European levels. Special attention will be given to the adaptive input-output modelling in estimating the broader cascading economic effects of adaptation of climate extremes.

2 Literature Review on upscaling method

2.1 Introduction

This chapter aims to provide a critical review of available methodological frameworks and approaches for upscaling cost and benefit of climate change adaptation. The chapter gives a general overview of upscaling approaches and introduces literature on several key sectors, including agriculture, ecosystem services, cities and infrastructure, water resources and health.

Although procedures are necessary to transfer data and methods between scales, the literature on upscaling climate change adaptation and mitigation data is relatively scarce. More literature is available about downscaling, 'the process in which coarse-scale data is disaggregated to a finer scale while ensuring consistency with the original data set'. For downscaling several criteria have been developed to guide development of downscaling procedures. The criteria for this procedure include consistency with existing local data, consistency with the original source, transparency and plausibility of the outcome (Vuuren et al, 2007). Similar criteria can be developed for upscaling procedures. For upscaling the local data needs to consistent with and representative for the area to which the upscaling is performed.

In general, three different types of approaches can be distinguished to scale up costs, benefits and effects of climate adaptation measures.

- The first is the *qualitative accumulation* of case-study evidence. Lessons learned from individual case studies can be advantageous for local and sometimes national policy (Burton et al, 2007). Databases with examples of (the effects of) adaptation measures, such as the UNFCCC databases on ecosystem based approaches to adaptation and local coping strategies to adaptation might provide some general lessons for policy makers. However, problems with the coverage of information and comparability of the studies complicate the use of the results at a higher scale (Burton et al, 2008).
- The second approach is a *meta-analysis*. With this approach comparable studies are collectively analysed to formulate generic relationships. The basis of this analysis is statistically synthesizing similar data in order to quantitatively pool and analyse the results. Therefore, an important condition is a similar structure and methodology of the compared studies (Burton et al., 2008). For example, the use of different metrics, scenarios or time periods will make the comparison of the effects of climate adaptation measures more challenging (Watkiss and Hunt 2012). Another factor that influences the quality of the up-scaled results is the difference in institutional conditions across countries (Rosenberger & Johnston, 2009).
- The last approach is *(adaptation) modelling*, which has the potential to up-scale technical and scientific modelling studies from local to global levels (Burton et al, 2008). Detailed spatial data are most of the time not available at a global scale. Therefore, indicators for global impact assessment are inevitably more generalised (Winsemius et al, 2013). Information from case studies can support the development or calibration of the models, as

well as improving damage curves used within the models. For example, in damage modelling calibration and validation is scarcely performed. One of the reasons is the scarcity of suitable data, case study data can potentially fill this gap (Merz et al, 2010). Another example is that many models use simplified assumptions, because of a lack of data. By using case-study information these assumptions can be improved. The most common up-scaling approach is the development and evaluation of (physical) parameters for global models with data from local or regional models. In many cases this means the substitution of heterogeneous property region consisting of fine grid cells with an equivalent homogeneous region made up of a single coarse- grid cell. Essentially, this is an averaging procedure in which static and dynamic characteristics of the fine scale model have to be approximated (Leung et al, 2005). For example, regional climate models can be used as test beds for the development of parameters to include in global climate models. Most scientists tend to use the finest spatial resolution possible to include the most details and spatial variation (Zhang et al, 2014). However, when a very detailed grid model is based on sparse data this may be misleading (Merz et al, 2010).

Discussing the upscalibility of climate adaption measures other matters arise. Since adaptation measures are an issue relevant at local, national and international level, it is in principle possible to characterise effective adaptation measures independent of the scale and context. However, the success of an adaptation measure depends on how that action meets the objectives of your own and others adaptation goals. Consequently, a successful measure for one individual does not have to be classed as successful by another. Therefore, the scale of implementation and the criteria used to evaluate the measure at different scales are important (Adger et al. 2005). Hence, the cultural and institutional context can hinder upscaling of climate adaptation measures. When considering upscaling climate adaptation measures, these contexts have to be taken into account.

Estimation of adaptation cost by Climate Cost project

The BASE project needs to come up with improved estimates of cost and benefits of adaptation to climate change upscaled and integrated into sectors at EU-level. This upscaling and integration is the main challenge of WP6.

There have been some previous efforts in estimating the costs of adaptation against climate change. Climate Cost Project has done a review of the studies done to identify gaps and potential needs in the climate adaptation cost estimate research area. Below a summary of the main observations derived from the 7th FWP Climate Cost Study (prepared by Paul Watkiss and Alistair Hunt)

- The coverage of adaptation cost estimates is limited, although the evidence base is growing
- Of all studies done, there is an uneven distribution of sectors
- Majority of studies have been done for the coastal zone sector on flooding

- The least amount of cost and benefit studies have been done on protecting biodiversity and ecosystem services and on impacts on industry and business sectors.
- The most comprehensive national adaptation cost assessments have been done in the Netherlands, Sweden and the UK.
- The least amount of information is available for new EU member states
- The assessments vary heavily in methodology and approaches; the use of different metrics, time periods, assumptions with regards to changing socio-economic conditions etc. which makes it challenging to compare

There are many EU adaptation costs studies done at different scales. Comparison across different scales remains challenging, due to several issues, which are addressed below.

Studies with global estimates: estimation based on global models, such as economic integrated assessment Models (IAM). Main issues:

- Very aggregated representation of impacts and adaptation
- Lack of technical detail
- No consideration of uncertainty or behavioural change
- Insufficient detail for national or sub-national adaptation planning

European and sector studies: Aggregated sectoral and EU wide impact assessments (eg. PESETA coastal study, energy and health studies). Main issues:

- Highly aggregated with simplified assumptions
- Coverage within sectors, omitting cross-sectoral, economy-wide effects
- Often only looking at hard (engineering) adaptation options,
- Medium to long term focus of impact assessment may mean less relevance for short-term policy

National and local studies: Many national level and case studies. They imply large adaptation costs, mainly for flood protection (total investment needs over time). They are difficult to scale up; the generally estimated adaptation costs are much higher than the adaptation costs as estimated by sectoral or IAM studies, due to:

- Most include current backlog of investment needs as well (current climate risks) or include investments that belong within the normal investment replacement cycles
- Main focus is on technical adaptation and omits possible behavioural change

- The marginal additional costs for climate change are rarely split from those induced by socio-economic change

One of the main objectives of WP6 will be to deliver an upscaling framework, a common grid along which lines analyses will be done. This is necessary to overcome the above mentioned short-comings of previous studies as Climate Costs has identified. The main issues are the following, which WP6 will aim to tackle as much as possible through this data exchange plan:

1. There is not one leading approach: There are huge benefits to be accrued by adopting multiple methods and models and link these together to provide a larger evidence base

2. There are different assessment tools: Studies use many different decision support tools, mostly used are cost-benefit analysis, cost-effectiveness analysis, multi-criteria analysis and pathways / real option analysis.

3. Different definitions and boundaries: Different interpretations of what constitutes adaptation, and what is attributed to climate change versus socio-economic change, current and future needs. There is often an overlap between impact (damage) and adaptation costs.

4. Focus on hard technical adaptation: Multiple options for adaptation should be considered, without bias towards hard options and less coverage of soft options. Often excluded are behavioural changes and adaptive capacity or autonomous adaptation.

5. Low sectoral coverage: For some (potentially important) sectors there is still a low coverage and very little information on adaptation costs (e.g. water supply, tourism, industry & business, biodiversity / ecosystems).

6. Need for validation: Current models involve high levels of aggregation and simplifying assumptions. Validation against more detailed, national and local level analysis (from the BASE case studies) is therefore needed.

2.2 Water availability and floods

This section aims to provide a critical review of available methodological frameworks and approaches in up-scaling cost and benefit of climate change adaptation related to floods and water availability.

2.2.1 Flood risk

In recent years more attention has been given to strategic flood risk assessments and their inclusion in global integrated assessments (OECD, 2012; Ward et al, 2013; Jongman et al., 2014). For example, UNISDR combined modelled and reported events to produce maps of population and GDP exposed (Peduzzi et al, 2009). A World Bank project estimated risk by combining gridded population and GDP with reported flood event data (Dilley et al, 2005). In the United Kingdom many regions make more local strategic flood risk assessments aiming to make informed decisions about emerging growth and allocation of land (Department for Communities and Local Governments, 2009).

Flood risk modelling basically comprises hydrological/hydraulic and flood impact modelling. The methods and models vary widely, as well as the scale of these models. In every part of the so-called cascade of models, up-scaling may take place. For example, this can be averaging precipitation data or transferring asset value data from one country to the other. The next sections will focus on the different elements of flood risk modelling and will identify some potentially up-scaling possibilities and problems.

2.2.1.1 Hydrological/Hydraulic modelling

There is a wide range of hydrological and hydraulic models available for modelling flood risk including ISIS, Mike-11, PCR-GLOBWB, Flo-2D, LisFlood and Tuflow (CH2MHILL, 2014; DHI, 2014; Utrecht University, 2014; Flo-2D, 2014; Knijf et al, 2010; BMT WBM, 2013). These models perform 1D or 2D modelling of water flows, sometimes supported with stage-damage functions (Banks et al, 2014).

When building a new flood model, the standard modelling process is as follows:

The first step is the selection of the optimum modelling approaches. The second step is building the initial model including the collection of new data. Thirdly, the model is tested, calibrated and validated and at last production runs and providing quality-controlled results (Wicks, 2012).

Within this process there are some possibilities to use more specified data as an input or as calibration or validation of the models results.

For example, PCR-GLOBWB uses meteorological data sets (air temperature, snow, rainfall and potential evaporation) and converts them to the same horizontal resolution. The maximum flood volumes per grid cell for a selected return period can be modelled or being based on real time series. If the flood volumes are too coarse, higher resolution hazard maps can be conducted with models such as GLOFRIS. This model scales down the flood volumes to higher resolution inundation depths. Nowadays satellite data from for example GRACE plays a major role in validating hydrological and hydraulic models. Further validation with field data is possible as well (Winsemius et al, 2013). For example, Ward et al (2013) estimated in PCR-GLOBWB discharges for both gauging stations and corresponding cells to improve validation.

Global or high scale hydrological and hydraulic models include no measures such as dikes and water retention areas. Consequently, the risk estimates do not incorporate this aspect, which will likely cause overestimations. Future improvements to these models will involve parameterization of this kind of measures (Ward et al, 2013).

Currently, the hydrological and hydraulic models used in flood risk modelling use (meteorological) datasets and real time data series as input for global flood risk estimations. Depending on the chosen grid size this data needs to be up-scaled or downscaled. This is mostly done through averaging, interpolation or extrapolation. Since for global flood risk models the data have to cover preferably the whole world, meteorological data from a single case study will not contribute to the accuracy of the models. However, (meteorological) data from case studies may contribute to regional hydrological and hydraulic models. For example, local gauges can be used for validation of the model. Adaptation measures are still lacking in global hydrological and hydraulic models, while in regional models these can be present. Case study evidence can potentially contribute to the parameterization of this kind of measures.

2.2.1.2 Impact modelling

Impact modelling is used to estimate tangible flood damages. There are different approaches possible to determine the impact. The most accepted and common method to assess flood damages is through stage-damage curves. Depth damage curves or functions represent relationships between flood depth and the resulting monetary damage. There are a lot of different approaches possible to compose these curves. For example, choices have to be made for the spatial scale (object versus area based), damage classes, cost base (replacement cost versus depreciated cost) and the number of hydrological characteristics included (Jongman et al, 2012). Moel and Aerts (2011) demonstrated that the uncertainty in depth-damage curves and asset values are much more important in damage estimation then the uncertainties in hydrology and land-use input. Therefore, the composition of the depth-damage curves is essential for a good performance of a flood model.

Besides stage-damage curves, there are other approaches that can be used to estimate tangible flood damages. For example, on a local scale an expert can survey individual properties to determine potential damages. On a larger scale an average damage amount per building can be adopted. Which method is performed depends on the level of flood risk and the quality of flood hazard information (Queensland government, 2002). Local data can improve the quality of these flood damage estimations.

The following procedure is mostly used for the assessment of direct monetary flood damage (Merz et al, 2011):

- Classification of the elements at risk by pooling them into homogeneous classes
- Exposure analysis and asset assessment by describing the type and number of elements at risk and the asset value
- Susceptibility analysis by relating the relative damage of the elements at risk to the flood impact.

The last two steps can also be combined within a single damage function.

Depending on the scale (micro-, meso- or macro-scale) the analysis takes into account a large number of elements at risk. Since there is mostly no information on damage behaviour of each object, a detailed assessment would require an enormous effort. Consequently, the elements can be pooled into classes that may obtain the same asset value. The damage of the classes may be estimated by using a susceptibility function. The details of classification depend on the resources available for assessment, data availability, heterogeneity of objects/classes (socio-economic structure, heterogeneity flood impact) and the relevance of objects/classes. However, there are still no classifications that are based on objective and statistical classification methods (Merz et al, 2011).

An exposure analysis recognizes the objects that are affected by a flood scenario. This can be done with the extraction of exposed objects by intersecting land use data with inundation data. The value of flood-affected objects can be used to estimate asset values. Most data on asset values are estimated on a coarse level. These values have to be downscaled to connect with the spatial scale of the results of the hydrological/hydraulic model (Merz et al, 2011). For example, this can be done with land use data.

Damage functions represent the susceptibility of the respective element at risk. Factors that influence damage can be differentiated into impact and resistance parameters. The first reflects the specific characteristic of a flood event for objects in the flooded area, whereas the latter depict the capability or incapability of an object to resist the flood impact. There are two main approaches that can be distinguished in flood damage modelling: empirical approaches that use damage data collected after flood events and synthetic approaches that use damage data collected with questionnaires (Merz et al, 2011).

Local studies usually employ the micro-scale view and derive damage estimates for each flood-prone object. Since this approach requires detailed, local input data and a large effort per unit area, meso-and macro scale approaches are frequently chosen to cover larger areas.

Besides direct tangible damage, indirect tangible damage may be a substantial part of the total damage. Indirect impacts are for example disruption of public services and induced production losses to companies outside the flooded area, cost of traffic disruption and other damage that does not insure directly and immediately damage from floodings. Indirect damages are much more difficult to measure then direct damages. Consequently, indirect effects are mostly calculated with models such as simultaneous equation econometric models, input-output models and Computable General Equilibrium models. The drawback of these models is that they often overestimate the indirect regional economic damages (Merz et al, 2011).

Validation

The aim of validating a model is to assess if the model is capable to realistically estimate the damage for a certain flood event. Additionally, it can be used if there are systematic errors or if damages are always under- or overestimated. Validation can primarily be performed on the micro scale and requires detailed data (single objects with repair costs, input data for the damage model or other parameters). However, validation is scarcely performed due to the lack of damage data. If this data is not available, there are other ways of validating a model for example, using expert knowledge, comparison of alternative damage models and methods for evaluating the process of model construction (Merz et al, 2011).

Shortcomings

One of the largest shortcomings of damage assessments is the assumed mismatch between the relevance of damage assessments and the quality of the available models and datasets. The main drawbacks are the limited available data, the scarcely conducted validation and limited knowledge on damage mechanisms. Reliable, consistent and comparable data is often lacking, because this data is rarely gathered, repair cost estimates are uncertain and data are not updated systematically. Especially damage data for small floods or local areas inclined to be inaccurate. However, in general there is no systematic under- or overestimation, consequently the estimations tend to average out on a higher scale (Merz et al, 2011).

Damage models can be transferred between elements at risk, in time, in space and in spatial scale. Although transfers in spatial scale are most relevant for up-scaling the other possible transfers are associated with up-scaling as well. For example, there is an enormous variation of damage between elements at risk. Even houses located next to each other can be unequally damaged due to different asset value, exposure etc. Although pooling of houses in differentiated classes can partly solve this inconsistency, uncertainty will always be there. Similarly, transfers in time show uncertainties. The environment is not stationary in time, vulnerability, asset values and susceptibility may all change. These changes are mostly not incorporated in models. Cammerer (2013) found that flood functions derived from related or more similar regions perform better than the ones from heterogeneous datasets (of different regions and flood events). In this study the losses to residential building are found to be a factor 18 higher when estimated with heterogeneous datasets without proper validation. Typically, damage models are based on micro-scale data. However, meso- and macro-scale damage assessments apply damage models for aggregations of elements at risk. The uncertainty due to scale can be rather small in comparison to the other transfers, but only if appropriate up-scaling procedures are used. Apel et al (2009) showed that meso-scale approaches can even outperform more detailed models.

Already in 1965, Kates proposed an adaptation option function that reflects adaptation of flood damage over time and space as a result of adaptation measures (Booysen et al, 1999). However, this idea is not yet implemented in damage modelling, mainly due to the lack of data (Merz et al, 2011).

Costs of adaptation measures

The costs of adaptation measures are in general easier to calculate than the benefits (avoided costs etc). Nevertheless, the costs of adaptation measures are largely influenced by local conditions such as risk perception, institutional organization and local behaviour. Mostly, the data on the costs of adaptation is locally achieved, but up-scaled for global models. However, most likely the costs do not remain constant when scaling up. For example, the transaction costs can be different per region as well as the costs of the activity itself.

2.2.1.3 Conclusions

According to Moel & Aerts (2011) the uncertainty in depth damage curves and asset values are larger than in hydrological and land use models. In theory, inserting local data from case studies to local or regional models will reduce the uncertainty, which will enhance the performance of flood (risk) models. For example, asset values are typically only available on a coarse level, if asset values would be available on the same scale as the grid of the hydrological model, downscaling would not be necessary. However, if the model performs on a regional scale, data from a large area have to be available. In addition, when transferring local or regional data to another region, the region needs to have similar characteristics.

One of the largest drawbacks of damage assessment is the lack of validation. Validation of models is basically performed on micro-scale and requires detailed data. Single objects with repair costs, input data for the damage model or other parameters can support validation.

2.2.2 Water availability

The United Nations performed the first global-scale assessment of water resources and their use in the United Nations Comprehensive Assessment of the Freshwater Resources of the World (Raskin et al., 1997). However, a deficiency of this assessment was the lack of a global modelling approach for water availability and use. Water stress indicators could be only computed for whole countries or even larger scales, because the necessary information was only available for these units. Additionally, the impact of climate change on water availability could not be assessed (Doll et al, 2002). To overcome these problems several global and regional water availability and water use models were developed, such as WaterGAP, WEAP, Ribasim, WaSSI, PCRGLOB-WB and Modsim (Climate Change Resource Center, 2013; Deltares, 2013; Alfarra et al, 2012). Most models consist of two parts, a water use model and hydrological model, which are linked to compute water stress indicators and calculate the reduction in water availability due to consumptive water use. The hydrological models are mostly tuned or calibrated with data input from gauging stations or satellites. The following factors could impede (hydrological) modelling of water availability (Doll et al, 2002):

- incorrect input data (such as precipitation)
- sub-grid spatial heterogeneity
- uncertainty of model algorithms (such as potential evapotranspiration or discharge reduction by water use)
- neglect of important processes like surface water-groundwater interaction and artificial transfers.

These factors mainly influence on the supply side and not on the demand side of water availability. Water use models have different impediments, such as uncertain about demographic and socio-economic growth, uncertainty in the way people use and manipulate water resources, limited availability of data and spatial heterogeneity. The spatial resolution of water availability models is rather coarse. These models will benefit from the refinement of the spatial resolution to give policy makers recommendations that are more specific and less uncertain (Alfarra et al, 2012). This will require local or regional data input. Currently, water use models aggregate water demand mostly on a city or country level, whereas in rural areas irrigation demand is often partitioned by crop type, cultivated area and crop demand (Alfarra et al, 2012).

Since the United Nations Comprehensive Assessment of the Freshwater Resources of the World study, many studies were performed on the impacts of climate change in the natural hydrological regime, whereas not many studies were conducted on the impact of climate change on the regulated system or the impact of socio-economic factors on climate change impacts on water resources. The studies that took socio-economic factors and climate adaptation in account were mainly about agriculture (Rosenzweig et al, 2004; Iglesias, 2012). Currently, models are developed that take into account the influence of socioeconomic factors on climate change impacts and climate adaptation measures. We will give two examples; BASE will further develop the WAAPA model (see deliverable 3.2), which computes water availability and reliability (demand-reliability curves) as a result of implementing climate or policy scenarios. The project Water2Invest financed by the Climate-KIC develops a model that assesses the impacts of both future water scarcity and of alternative measures to reduce this scarcity under different climate scenarios (Van Aalst et al, nnb).

Similar to flood risk, limited information is available on up-scaling water availability studies and models. There are examples of qualitative accumulation of case-study evidence including upscaling of adaptation measures (FAO, 2012), calibration of hydrological models with data input of gauging stations (Doll et al, 2002) and aggregation of water demand data (Alfarra et al, 2012). The use of local/case study data in combination with a good up-scaling approach can possibly reduce the factors that hinder modelling water availability, such as incorrect input data and sub-grid spatial heterogeneity. Information on the type and effect of local climate adaptation measures may improve the models that take into account the influence of socio-economic factors on climate change impacts and adaptation measures. However, the transferability of the data depending on the comparability of the methodology, approaches and the characteristics of the region will remain the main condition for up-scaling data.

2.3 Agriculture

2.3.1 Process-based models of crop productivity.

Process-based crop models are site-based bio-physical models that are increasingly used to estimate productivity and food supply under climate change (Ewert et al, 2005). Examples of analyses using this approach comprise Rosenzweig and Parry, 1994; Harrison and Butterfield, 1996; Nonhebel, 1996; Brown and Rosenberg, 1997; Downing et al., 1999; Easterling et al., 2001; Parry et al., 2004.

At a regional level, Easterling et al., 2001, use process-based crop models and adaptive management strategies at farm-level under high (0.5° horizontal resolution) and low resolution (5° horizontal resolution) climate change on the great plains of the U.S. to test whether applying a finer scale of climate impacts would influence the effectiveness of adaptation on crop yield (with and without the direct effects of CO2). Adaptive strategies comprise earlier planting and switch to longer-season cultivars. At the time of the study, Easterling et al., 2001 were the first to include high resolution soil details in the analysis of adaptation to climate change in agriculture. Soils with good drainage and water holding capacity can better mediate the effects of climate variability on crops than poorly drained soils.

Also at a regional level, but through the construction of representative farm types, Brown et Rosenberg, 1996, use the Erosion Productivity Impact Calculator (EPIC) model to study the impacts on yields, water use efficiency and evapotranspiration with four crops (corn, soy bean, wheat and sorghum) under a variety of climate scenarios, but without accounting for adaptive strategies. Climate variables included temperature, precipitation, solar radiation, humidity and atmospheric CO2 concentration conditions. The five representative farms were developed to represent the agriculture practiced in four Major Land Resource Areas (MLRAs). Current productivity was simulated based on a 30-60-year EPIC simulation under the then present-day climate and then averaged to produce crop yields and water use. Using rational rules of climate representations, simulations proceeded to single and multiple combinations of the various climate and plant growth variables. Results were developed on single factor effects and multiple factor effects and come up with a range of possible effects on crop yields and water consumption when all important climatic elements were considered individually and interactively.

Taking the case of wheat, Nonhebel (1996) uses historic daily weather data from 13 sites in Western Europe (Scotland to Northern Italy and from England to Germany) as a starting point in the crop-growth-simulation model (SUCROS87) to study effects of temperature rise and direct effects of CO2 on yield. The study does not account for adaptation actions by farmers. The model simulates yield under optimal conditions (no water limitation) and with water limitations. Water availability was modelled as differences in soil quality, using hypothesised data with very low water-holding capacity (200mm m^{-1}) to signify limited water availability to crops. Flooding was not included and as in the above mentioned studies, other stresses on crops were excluded. Results of temperature and direct CO2 effects were like in Brown and Rosenberg (1997) considered individually and combined for the 13 sites. Precipitation patterns were considered separately.

Process-based models encounter a number of limitations: i) important yield restricting factors are often not accounted for (e.g. pests and diseases, soil salinity and acidity, atmospheric pollution); ii) actual yields remain difficult to simulate; and iii) advances in technology and crop variety that help improve productivity are not included, although these factors have largely been responsible for obtained yield increases over past decades (Ewert et al., 2005; Landau et al, 1998; Jamieson et al., 1999; Ewert et al., 2002; Evans, 1997). Also most studies assume that farmer have full climatic foresight and are able to respond to climate change as the changes unfold, i.e. an optimal adaptive capacity (Easterling et al., 2001).

Relatively many examples exist of process-based models being used for up-scaling at regional or larger scale to quantify effects of climate change on agricultural output at the European level (Downing et al., 1999; Nonhebel, 1996); at US level (Izaurralde et al., 2003; Easterling et al., 1993, 2001; Reilly et al., 2003; Brown and Rosenberg, 1997); and globally (Parry et al., 1999, 2004; Tan and Shibasaki, 2003; Rosenzweig and Parry, 1994).

However, only few studies have explicitly evaluated the performance of the up-scaling procedures from site to regional scale (Easterling et al., 1998; Olesen et al., 2000) and results of the validations give only limited confidence in the capacity of process-based models to predict regional scale changes in productivity under climate change (Ewert et al., 2002; Tubiello and Ewert, 2002).

2.3.2 Statistical models

As process-based field models have difficulties capturing the relationships that determine regional changes in actual yields (i.e. unsatisfactory up-scaling of changes in productivity), statistical models have been developed and applied as an alternative.

Statistical models are able to describe relatively simply the important relationships that determine regional changes in yields. They take historical data on crop yields and weather to calibrate the regression equations. Three main types of statistical approaches are found in the literature (Lobell and Burke, 2010):

- Variations over time from a single point or area (time-series methods) – these generally have the advantage of capturing the behaviour of specific areas but are limited by data availability
- Variations in both time and space (panel-methods) – these assume common parameter values across sites but can aggregate data from multiple sites; and
- Variations in space (cross-section methods) – these assume common parameter values across sites, can aggregate data from multiple sites but omit variables such as soil quality of fertilizer applications.

General advantages of statistical models compared to process-based models include a limited reliance on field calibration data; transparent assessment of the performance in predicting crop yield responses to climate signals (Lobell and Burke, 2010).

However, statistical models are technically limited by the underlying dataset and cannot predict future productivity if future conditions lie outside the range of present and past conditions (Ewert et al. 2005); also, statistical models are subject to problems of co-linearity between predictor variables and low signal to noise ratios in yield or weather records in many locations (Lobell and Burke, 2010).

Lobell and Burke (2010) evaluate the ability of the three different typologies of statistical models to predict yield responses to temperature and precipitation change under climate change for nearly

200 sites in Sub-Saharan Africa compared to the process-based CERES-Maize model. They find that all three types of statistical models produce better results when estimated at broader spatial scales than when estimated at individual site scale. Time-series models were able to reproduce site-specific yield response to precipitation change but were less able to predict yield changes to temperature changes. The opposite was found for the cross-sectional and panel-data models.

2.3.3 Scenario-based predictions of future crop productivity

Scenario development has evolved as an alternative to or in combination with statistical models or process-based models of crop productivity under climate change, notably based on the SRES storylines. Scenarios allow productivity effects in agriculture to be modelled outside the range of historic conditions. They represent coherent, internally consistent and plausible descriptions of future developments and can integrate bio-physical and socio-economic dimensions.

Rounsevell et al. (2005, 2006) developed a coherent set of future land use change scenarios for Europe for 2020, 2050 and 2080. First, a qualitative interpretation of the four SRES storylines for the European region was conducted; second various land use models were used to estimate the aggregate totals of land use change (urban, cropland, grassland and forest land); thirdly the aggregates were allocated using spatially explicit rules. The allocation was further downscaled from a resolution of 10 min to 250m using statistical downscaling methods. The main aim of the exercise was to analyse the vulnerability of ecosystem services, but also provides the opportunity to explore how agricultural land use may respond to climate and socio-economic drivers including technological development. They find that for all four scenarios technological development would lead to a decline in the need for agricultural land use in Europe to varying degrees, if the technology continues to progress at the current rate.

Ewert et al. (2005) were among the first to carry out an analysis of crop productivity changes using scenario-based analyses of land use change. They use i) the land use change scenarios developed by Rounsevell et al. (2005); ii) a statistical analysis of historic yield trends for major European crops; iii) the supply-demand model and model of effects of technology development by Rounsevell et al. 2005; iv) a simplified statistical approach to estimate the effects of direct CO2 of crop productivity and v) climate stratification for Europe and changes in climatic conditions for 2020, 2050, and 2080 to calculate yield changes by strata and by scenario. The yield changes induced by climate change were spatially represented for Europe, taking wheat as a reference crop for Europe.

At a global level, Parry et al. (2004) couple biophysical yield transfer functions with a world level general-equilibrium model to assess the impacts of and adaptation to a changing climate on global food production and trade. They build on their previous work (Parry et al. 1999). The bio-physical analysis is based on yield transfer functions derived from dynamic crop simulation models, which incorporate i) crop responses to changes in temperature and precipitation under current management; ii) crop responses to temperature and precipitation under adaptation to changing climate regimes at farm- and regional level; and iii) crop responses to increasing levels of carbon dioxide. The analysis looks at four crop types representing approximately 85% of world cereal export (wheat, rice, maize and soybean) and extrapolates to other crops and commodity groups.

Dependent variables selected to enter the transfer function were first identified by investigating correlation coefficients between crop yield and temperature and precipitation anomalies over the full crop growing period. Yield responses were taken from results of more than 50 regional climate change impact studies looking at different crop responses to climate variables. The agroclimatic regional yield transfer functions were then estimated in a statistical analysis of the combined effects of changes in temperature and precipitation on yield responses. The transfer functions from each agroclimatic region were then applied to spatial climate change data, which were based on four SRES scenario changes in regional temperature, precipitation and assigned CO2 levels for the periods 2020s, 2050s and 2080s. The crop production models included in Parry et al. 2004 assume control for weeds, diseases and insect pests and that there are no problems of soil conditions; also the models account for droughts but not flooding of fields; assume homogenous agricultural systems within similar agro-ecological zones and constant farm technology over time.

Iglesias et al., 2012 apply a similar methodology as Parry et al. (2004) by combining a detailed evaluation of process-based site models and empirical production functions. They develop European scenarios of agricultural change for the 2080s, based on A2 and B2 SRES storylines and two global climate models downscaled across Europe, and identify changes in nine European agroclimatic regions. Selecting nine sites to represent the major agro-climatic regions in Europe, they apply the DSSAT crop models for wheat, maize and soybeans at each site to estimate crop responses to climate and adaptive management. The output of the crop models including sensitivity analyses was subsequently used to define statistical models of yield response for each site, which then represent the nine European agro-climatic regions. Changes in crop productivity were then used in the GTAP general equilibrium model to derive potential economy-wide impacts of changing agricultural productivity due to climate change.

2.4 Ecosystem services

2.4.1 Climate change impacts on ecosystem services and biodiversity: Scaling up, value transfer

This section follows on chapter 2.6 of deliverable D4.1, where approaches to the valuation of climate change impact on ecosystem services and biodiversity are described

Nunes and Ding (2009) estimate that climate change impacts on biodiversity and ecosystem services leads to substantial economic losses of about 145-170 billion US$ for the forty four European countries. These losses include climate change impacts on forest carbon sequestration, biodiversity productivity effects on agriculture and impacts on freshwater and coastal ecosystems.

The need for the economic valuation of change in ecosystems across large geographical scales has been stressed by TEEB (The Economics of Ecosystems and Biodiversity) initiative. Within the 'scaling up' approach, existing economic values data on local ecosystem services are used for an assessment of the values at a larger geographical scale. In general, scaling up approaches are extensions of value transfer, builds on methods and tools developed for value transfer (EEA, 2010).

Brander et al. (2012) applied an upscaling approach to value climate change induced losses on European wetlands for the period 2000–2050. The methodology used meta-analysis to produce a value function. Expected changes in wetland extent due to climate change were examined based on scenarios. Results show that the annual value of lost European wetland ecosystem services in 2050 is estimated approximately 1 billion US$ (2003 prices).

2.4.2 Models used to assess ecosystem services and biodiversity

Adaptation strategies and measures can have significant side-effects influencing the provision of ecosystem services and biodiversity. In this respect, ecosystem service and biodiversity modelling allows the assessment of both positive and potentially negative impacts of adaptation measures. Among an extensive number of modelling tools, this section gives an overview of InVEST, ARIES and GLOBIO3 models that provide the opportunity to model a wide variety of ecosystem services as well as biodiversity levels.

With respect to the approaches to scale up cost, benefits and effects of climate adaptation measures, ecosystem services models address mainly the third approach: adaptation modelling. Within this approach, data from local level are up-scaled to regional or global level. In BASE, the InVEST modelling approach utilizes data from local case studies, literature review in order to upscale the ecosystem service modelling to the European-wide level.

2.4.2.1 InVEST modelling tools

InVEST (Integrated Valuation of Environmental Services and Trade-offs) has been developed within the Natural Capital Project at Stanford University, USA, and presents a suite of freely downloadable modelling tools. The main asset of InVEST lies in its ability to provide information on prospective trade-offs among various ecosystem services, which are plausible to occur under different future scenarios (Kareiva et al., 2011). InVEST operates as an ArcGIS extension, as well as an independent tool for Microsoft Windows, and can be utilized on various spatial scales, from local to global (see section 2.4.2.2).

InVEST tools provide spatially explicit outcomes in the form of ecosystem-service provision maps. Subsequently, trade-offs between different ecosystem services can be easily quantified. Therefore, InVEST produces both scientifically valuable and easily conveyable information, which can be utilized both by scientists and decision-makers.

One of the main data inputs into InVEST models are land use and land cover (LULC) maps, depicting both the current and future states of the study area. Future LULC maps are supposed to convey plausible development of the study area and thus serve as future scenarios. Various driving forces and their impacts can be incorporated into these scenarios and rendered through changes in LULC. Therefore, climate change scenarios and adaptation scenarios translated into LULC scenarios are especially suitable to be utilized within InVEST. In addition, InVEST models require an array of other ecological and socio-economic parameters, depending on the module focused on the module utilized (Tallis et al., 2011).

InVEST models are divided into several tiers, allowing for both biophysical and economic evaluation. Therefore, InVEST can be utilized to assess the costs and benefits of various adaptation measures and strategies, incorporated in adaptation scenarios, in terms of ecosystem services provision.

In the case of InVEST, following terrestrial ecosystem services can be evaluated:

- Habitat quality and rarity,
- Carbon storage and sequestration,
- Reservoir Hydropower Production,
- Nutrient discharge and retention,
- Sediment retention,
- Managed timber production,
- Crop pollination.

2.4.2.2 InVEST applications

InVEST modelling tools have been applied in several studies worldwide at global, regional as well as local scale (Nelson et al., 2009; Nelson et al., 2010; Goldstein et al., 2011; Cardinale et al., 2012; Johnson et al., 2012) in order to analyse future scenarios and project changes in provision of particular ecosystem services.

Global scale application

For instance, Nelson et al. (2010) performed a global analysis projecting global land-use change effects on provision of ecosystem service and biodiversity. Changes in global area of urban land and cropland for two scenarios of 2000 to 2015 have been assessed. Besides, consequences of these changes on ecosystem service provision, particularly on crop production, water availability, carbon storage and species habitat as well as trade-offs among these services, have been analysed.

Local scale application

Example of applying in InVEST modelling at local scale is ecosystem service trade-offs analysis performed to assist private landowner in Hawaii in decision making regarding design of a land-use development plan (Goldstein et al., 2012). In this case study, InVEST was applied to evaluate environmental and financial implication of seven land-use scenarios, which shows trade-offs between ecosystem services such as carbon storage and water quality as well as environmental improvements and financial revenues.

<u>*Modelling climate change impacts on ecosystem services*</u>

InVEST modelling tool can be applied to model the climate change impacts on ecosystem services as these models link land use and land cover (LULC) to provision of ecosystem services. While combining LULC data with climate projections, it is possible to explore potential future impacts on ecosystem services.

For instance, in the Willamette Basin of Oregon, climate change impacts on ecosystem services, particularly irrigation demand and carbon sequestration together with biodiversity has been assessed utilizing InVEST. Based on the SRES mid-high A2 emissions scenario, most of the Basin is projected to experience decrease in water yield, with increase irrigation water demand at least 50% by 2050. In general, climate change is expected to have a negative effect on carbon storage and on terrestrial vertebrate diversity expressed by decrease in countryside species area relationship (SAR). SAR scores decreased from 5.18 to 7.68% between the years 2000 to 2050 (Lawler et al., 2011).

Arkema et al. (2013) explores the role of coastal habitat in protecting U.S. communities from extreme weather events and coastal erosion. While using five sea-level-rise scenarios, InVEST, synthesizing existing hazard models, climate scenarios, demographic, economic, and ecological data, the authors produced a U.S. nationwide map of risk reduction due to existence of natural coastal habitats. Coastal ecosystems serve as natural defence against coastal storms as well as climate-induced sea level rise. The results show that the number people, households, and total value of residential property exposed to the hazards can be reduced by half by 2100 if existing coastal habitats stay fully intact.

2.4.2.3 Other models assessing ecosystem services and biodiversity

ARIES (Artificial Intelligence for Ecosystem Services) is a suite of web applications aimed to assess ecosystem services, map benefits, beneficiaries, and service flows in order to support efficient environmental decision-making. To describe the distribution of benefits across the landscape, ARIES methodology combines spatially explicit models of ecosystem service provision and use with dynamic flow models (Villa et al., 2009). The ARIES tool defaults to probabilistic relationships that are based on data stored from other similar sites around the world. In cases, where sufficient local data are available the tool can employ biophysical relationships. ARIES also uses artificial intelligence methodologies to improve the functional relationships and decrease the level of uncertainty (Vigerstol and Aukema, 2011). Currently, the tool covers following ecosystem services: carbon sequestration, flood regulation, sediment regulation, aesthetic view and proximity, freshwater supply, subsistence fisheries, and recreation. Only preliminary version of ARIES for selected case study regions is available online.

GLOBIO3 (Modelling human impacts on biodiversity) is a modelling framework designed to calculate the impact of environmental drivers on biodiversity for past, present and future, at regional and globe scale. The GLOBIO3 model assesses the proportion of autochtonous species present in a study area in comparison with its intact state, producing biodiversity indicator, the Mean Species Abundance (MSA) index. In addition, it enables modelling of ecosystem extent. The model is built on simple cause-effect relationships between environmental drivers and biodiversity impacts, based on literature. Environmental drivers include land cover change, land-use intensity, fragmentation, climate change, atmospheric nitrogen deposition, and infrastructure development (Alkemade et al., 2009). GLOBIO3 modelling framework consists of a model for terrestrial ecosystems and a model for the freshwater environment. Similar model, EcoOcean has been developed for marine ecosystems.

2.4.3 Ecosystem services value transfer

'The value of the world's ecosystem services and natural capital' is the most famous example of up-scaling ecosystem services values. In this study Costanza et al (1997) estimated the current economic value of 17 ecosystem services based on published studies and some original calculations. The release of this study raised discussions about the applied method. Basically, this method takes a value of a finished ecosystem service study and divide this by the area of the landscape type, the total value can be found by multiplying the unit value of this service by the land of this type. One of the main critics is that the ecosystem services value of the studies sites are poor matches for the global ecosystem under consideration. Since value is not intrinsic to a particular site or ecological system, it must be evaluated in the context of specific biophysical and human characteristics (Bocksteal et al, 2000) Nevertheless, value transfer is still a frequently used method for transferring or up-scaling case study values.

Value/benefit transfers can be defined as estimating benefits for one context by adapting an estimate of benefits from some other context. Currently, benefit functions are frequently used to transfer values. This function can be estimated with a meta-analysis of the study results, which is similar to other approaches, but can incorporate case characteristics as well. This allows adjusting the characteristics of the population and study area to the studied region. Also GIS applications can be used to estimate a spatially sensitive valuation function. Another frequently used approach is the (direct) transfer of unit values. According to Bateman et al (2011) unit values will be more appropriate for transfers or aggregation for relatively similar sites. Another way to transfer benefits is to calibrate the parameters of a utility function pre-determined by the benefit-transfer practitioner. Here the researcher makes an assumption about the functional form of the utility function in relation to the characteristics for the case. The calibration uses the estimates to shape a specified preference function (Smith, 2006). In summary, the best approach depends on the characteristics of both the valued site and the site to be valued.

It is recommended to consider five type of differences in the transfer/upscale process (Rolfe, 2006; Rolfe et al, 2013).

1. Site differences,
2. Valuation framing differences
3. Scale differences
4. Population differences
5. Statistical modelling issues

Adjustments can be made for this variety of influences in for example benefit functions. Scaling up value estimates from local level case studies to higher level case studies will cause specific difficulties. In willingness to pay studies, which are mostly the source of value estimates of ecosystem services, there is a correlation between the ratios of the quantities involved and the willingness to pay estimates. This can be corrected with scale adjustments (Rolfe et al, 2013). Another potential inaccuracy is the transfer of errors in the original willingness to pay study to a different scale, this may enhance these errors.

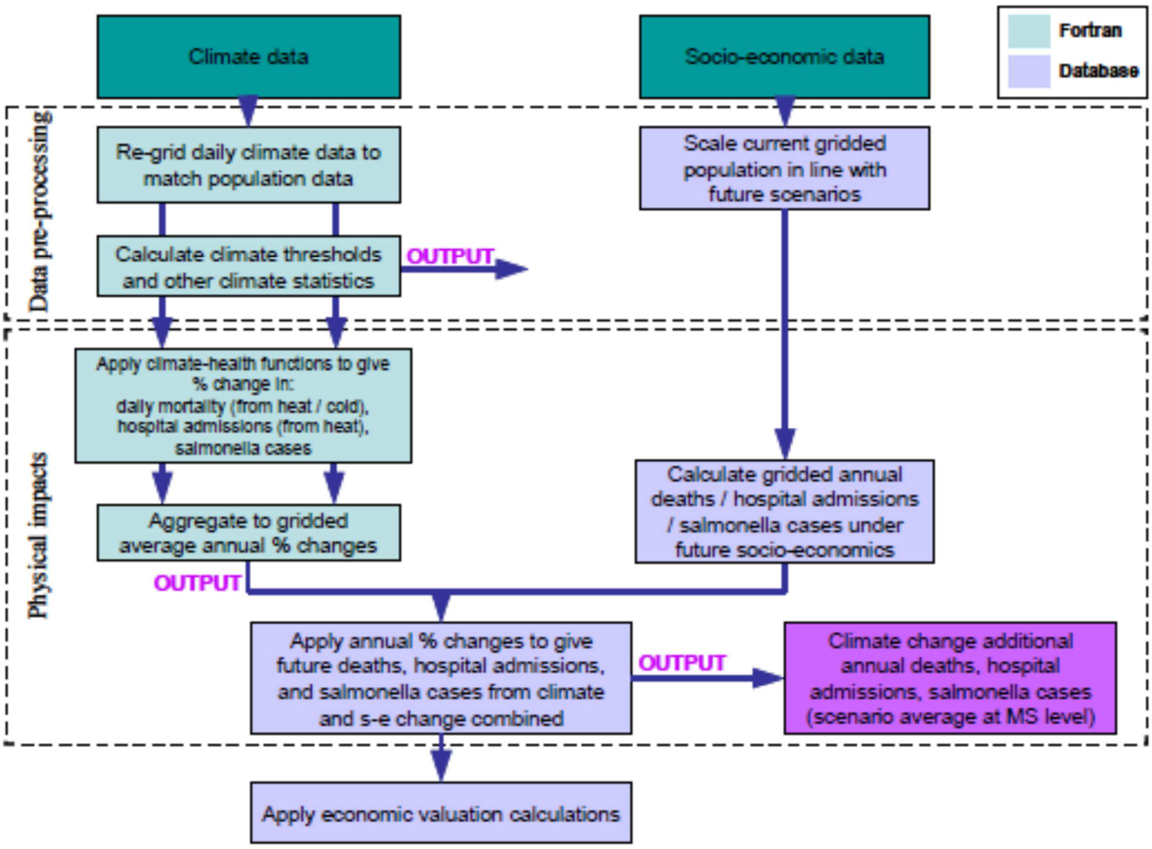
A set of steps or guidelines can improve benefit transfers for the valuation of ecosystem services. The following steps are recommended. Firstly, the analyst describes the policy site and the proposed policy including physical characteristics and the use of this site by humans. Secondly the analyst selects suitable existing studies to provide a basis for a benefit transfer. It is important that these studies cover the same type of uses or non-use (values) that are affected by the policy and that the site characteristics are similar to the policy site (Plummer, 2009). The studies have to meet the standard data requirements, such as sufficient data, a reliable method and empirical technique (Rosenberger & Phipps, 2007). The last step is the actual transfer. If only one study is available this can be done by using a similar method as Costanza (1997) did, estimating a unit value that is expressed as a constant per unit amount multiplied by the projected quantity of use at the policy site. This method is also preferable if the policy site and the site from the study have similar characteristics. If more studies are available a benefit function can be estimated with a meta-analysis of the study results. If study results are seriously up-scaled it is recommendable to use the necessary adjustments. Rolfe et al (2013) explains how to make these adjustment with a calibration relationship.

2.5 Health

Recent studies on the health cost of climate change in Europe have applied broadly similar approaches, based on the transfer of results from epidemiological studies to other countries and regions or, where the data allows, time series analysis of the impacts spatially. An overview of the PESETA modelling framework is given in Figure 2.1 below, as an example of the approach. Climate and socioeconomic data are combined to allow the identification of the physical impacts, and additional cases due to climate change are isolated from those caused by socioeconomic change.

The methodologies applied are broadly similar for most cases between e.g. ClimateCost and PESETA, for instance, which is not surprising given that these studies were conducted by similar teams and focussed on similar impacts. The main advance between ClimateCost and PESETA was the inclusion of impact functions based on improved epidemiological work – with e.g. improved functions for heat and cold mortality and improved consideration of changing baseline conditions (e.g. in terms of policy change or changes in acclimatisation assumptions for heat).

Figure 2.1: Peseta modelling framework



Source: Watkiss et al (2009)

Table 2.1: Methodological overview of selected recent studies

Impact	ClimateCost	Ebi (2008)	Peseta
General	Combines climate and socioeconomic projections with climate-impact response functions, with impacts valued in monetary terms	Combines climate impact responses with current distribution of diarrhea, malaria and malnutrition and uses current treatment costs	Combines climate and socioeconomic projections with climate-impact response functions, with impacts valued in monetary terms
Heat mortality	Used pooled European epidemiological functions from PHEWE project (Baccini et al, 2008). Assumed a change in heat threshold of 0.5C per 30 years.		Uses two methods to estimate heat and cold mortality. The first is based on country specific functions identified under the cCASHh project. The second is based on estimating the heat and cold thresholds at 50x50km grid cell level and then applying single functions for heat and cold mortality. Considers acclimatisation based on Dessai (2003) with a 1C acclimatisation assumed every 30 years.

Food borne disease	Used pooled estimate for impact of climate on salmonellosis cases based on time series study conducted in Europe (Kovats et al, 2004). Baseline assumed 20% reduction from 2000 to 2030, 2030 to 2050 and 2050 to 2080 to account for improvements in food hygiene regulation.		Applied functions linking salmonellosis to temperature drawing on available functions in a number of EC countries, drawing on Kovats et al (2004). Where no relationship existed, applied relationships from geographically/socially similar countries.
Coastal flooding	Assessment of direct risk of death from coastal flooding based on CRED (2011) EM-DAT database of annual average deaths due to storm surge.		Order of magnitude assessment of impact on incidence rates in flooded communities based on e.g. Reacher et al (2004)
Labour productivity	Bases assessment on the model for labour productivity linked to wet bulb globe temperature and labour productivity linked to work intensity, drawing on ENSEMBLES (Kjellstrom et al, 2009)		

AD-WITCH currently uses a calibration based on Tol (2002) and costs of adaptation based on WHO(2008). In BASE, in WP3 we are synthesising the existing literature base based on bottom-up estimation to improve on the existing coverage of impacts and adaptation options. This will allow a better estimation of the climate change impacts and adaptation policies undertaken in the AD-WITCH model, by taking into account the recent developments in upscaled health adaptation costs and benefits stemming from ClimateCost, Peseta, Ebi (2008) and other studies.

In terms of the case studies in WP5, it is unlikely that these will be able to be scaled to European level – because of the nature of the studies and the limited geographical coverage offered by two regional studies (in UK and Spain) and one national study (UK wide for mental health). However, these can inform the development of the marginal adaptation cost curves, albeit to a limited extent.

2.6 The urban context: estimating cascading economic effects of hazards using IO techniques:

Disasters can cause physical destruction to built-environment and networks, such as transportation and lifelines, and these damages are called direct losses. Direct losses then lead to interruptions of economic activities, production and/or consumption, and the losses from business interruptions are often called the indirect effects of disaster. In the other words, the local damage caused by local hazards can be cascaded beyond the impacted region to a wider economy at national and international level through the production supply chains. The upscaled economic impact (including both directly at local level and indirectly at wider economic level) should be evaluated and considered in adaptation and mitigation of climate hazards

Many scholars have chosen inter-industry input-output models for analysis because of their ability to reflect the structure of a regional economy in detail and to trace economic interdependence between the regions by calculating indirect effects of disruptions.

2.6.1 HAZUS: the Indirect Economic Loss Model

HAZUS is a multi-hazard loss estimation methodology, developed by the Federal Emergency Management Agency and the National Institute of Building Sciences, and later it has been developed to a software, where Rose and Cochrane (the other pioneer in applying IO techniques in risk analysis) were among the contributors. The software is based on the data from a geographic information system and is intended to simulate the direct and indirect economic effects of a specific natural hazard, like earthquake, flood or wind storm. The HAZUS is essentially IO based but hybrid with lifecycle household consumption model that means the household spending is endogenous in HAZUS. The Indirect Economic Loss Model component of HAZUS uses the post disaster surviving capacity in terms of a part of surviving production as a starting point for recalculating inter-industry supplies and demands.

This is done as follows. The algorithm determines the impacts on the inter-industry sales and purchases by means of row and column-wise multiplications of the transactions table with the factor of survived capacity. Following this procedure, first inter-industry inputs are multiplied (input-output transactions matrix columns) by the respective percentage of the sector's post disaster capacity, then shipments (input-output transactions matrix rows) are multiplied by the surviving capacity. Finally, the algorithm adds the pre-disaster final demands (households, government and exports) to arrive at a complete measure of excess supply and demand by sector. The algorithm of the module then identifies and balances the shortages and excesses. If excess demand is detected, the algorithm searches for a way to adjust sectoral capacity to account for unemployed resources in the region, and by importing from other regions, which are user-defined. If excess supplies are detected, the algorithm searches for alternative means of disposing those supplies, i.e. through export. The model adjusts potential outputs iteratively, depending upon the unique characteristics of the economy under study, until all net excesses are eliminated.

The strength of HAZUS is that it represents one of the most complete methods to model ex-ante and ex-post disaster consequences in an integrated manner, with an explicit geographical component. However, the model hinges on a number of specific assumptions. Unusual for input-output analysis, is the treatment of rows as columns of transactions matrix according to the surviving production capacity, while resulting coefficients and multipliers are interpreted in the conventional input-output sense. The reason is the assumed stability of technological coefficients, i.e. column-wise proportions within each sector; that's why, if the input-output transactions matrix is also multiplied row-wise, vertical proportions become altered and need new interpretation or modification (Rose & Chen, 1991).

In summary, HAZUS model was the very first integrated model to use input-output analysis to estimate the indirect costs of a disaster event. It demonstrate the important and significance of indirect costs can be. From the methodology point of view, HAZUS extends the conventional input-output table with detailed household sectors in order to capture the effects different household can have during a disaster. In MDM model, we can also capture this feather since the core model of MDM is a Social Accounting Matrix, which contains detailed household and expenditure data.

2.6.2 Backward and forward linkages in modelling economic cost of a disaster

The notion of backward and forward inter-industry linkages to identify the key sector was initially introduced by Hirschman (1982). According to Hirschman, backward linkages are related to the stimuli going to sectors that supplied the inputs for a given activity, whereas forward linkages are related to the inducement to set up new activities using the output of the given activity (Hirchman, 1958, p.100). This method has been applied in numerous studies (e.g. Aroca, 2001; Duarte, Sánchez-Chóliz, & Bielsa, 2002; Karkacier & Gokalp Goktolga, 2005; Kwak, Yoo, & Chang, 2005; Lenzen, 2003; Mohan & Dasgupta, 2004; Rimmler, Kurttila, Pesonen, & Koljonen, 2000). Van der Veen and Logtmeijer (2005) used backward and forward linkages to illuminate the so-called economic hotspots as a result of this hypothetical calamity, mapping those spots in terms of economic activity in the flooded area which would cause most of the (indirect) losses elsewhere in the country. They extended this damage concept with the indirect economic effects on the rest of the regional and national economy on basis of a bi-regional input output table. Similarly, Hallegatte (2008) used both backward and forward linkages to identify the key economically vulnerable and recovery sectors in Louisiana economy pre and after the Katrina.

2.6.3 Applying social accounting matrices (SAMs) in modelling natural disasters

Cole contributed a great deal to the development of input-output techniques applied in relation to risk analysis, especially to earthquake analysis. Cole et al (1993) used social accounting matrices (SAMs) to measure the consequences of planned and unplanned economic events in small island economics. The SAM provides an insight into the link between input-output tables and the so-called sector account, which include factors and institutions. The SAM particularly focuses on the representation of consumption and factor remuneration. Also, the activity part of a SAM is identical to the input-output table, although the level of aggregation is usually much greater. Differences between the other parts of a SAM are substantial. This reflects the diversity in purpose among users of the SAM.

Cole's model was constructed on the basis of past disasters, and simulative models were produced for the specific areas most prone to the impact of natural hazards. The approach offered by Cole et al (1993) and his following work uses a so-called Event Accounting Matrix (EAM), whose elements correspond to the entries of the SAM. Such a matrix is constructed so that it enables the mapping of the direct impact of the disaster onto the SAM. As Cole states: the EAM records the intensity of the impacts on each activity and transaction in the first instance, and the response of each activity or transaction after a disaster in the second instance. With the help of an EAM, a system's vulnerability and adjustments can be modelled and the results can be used to design strategies for regions prone to natural disasters. The authors also suggest that such a technique can be developed further into a full-fledged expert system for use in post-disaster economic recovery efforts, which could in turn provide a framework for the integration of a sector-specific expert system in transport and water supply systems and other activities in the public and private sectors.

In Cole's following studies Cole (2004; 2004) proposes a model to analyse how disasters and their consequences affect social actors and propagate throughout society. The focus of these works of Cole is the preparedness for disasters and survival strategies, which should improve societies' capacity to face adversities and recover from them. Purchase of formal insurance, maintenance of stocks, provision of a duplicate water supply system or even maintenance of social networks can be seen as investments; at the same time, these precautionary measures come at a cost. The opportunity cost of the resources used for investments in the buffer cannot be put into production, increasing welfare in business-as-usual times. In more technical terms, ex-ante preparations and spending on protection are leaking out of an input-output table, and in effect remain idle before disaster strikes. This means that investments in preparedness can be accounted for in a special added row as costs and column as sources) of a SAM matrix. With this additional account, a SAM becomes what is called an insurance accounting matrix. When modelling the post disaster situation, the benefits of precautionary investments in terms of lower costs and faster recovery can be identified. Then, these benefits can also be weighed against the costs incurred, but also against the ripple effects which are not realised because part of resources were taken out of the system. Cole's approach allows a demonstration of how contingencies and protection in one sector or in one segment of society can affect vulnerability of another, as well as examine the optimal level of protection investments to be made.

2.6.4 Supply side input-output modelling in disaster analysis

Another input-output based model on the international arena is one presented by Santos and Heimes (2004). They offer what they call the inoperability input-output model for studying the disturbances due to terrorist attack. Within an input-output framework, the authors use decomposition analysis to arrive at the description of how terrorism-induced perturbations can propagate throughout an entire economic network resulting from system interconnectedness. In essence, inoperability was defined as normalised production loss, where decreased production due to a disturbance is related to the 'as-planned' production level. Ultimately, an input-output type of equation is obtained, which is an alternative representation of conventional output final demand modelling. The model uses a Ghosh-type coefficient matrix, which is, essentially, the supply-side input-output model (Ghosh, 1958). It relates the inoperability output to the demand side perturbation that is also normalised according to the as planned output level. The model is an example of an input-output modification for calamity modelling, although does not include a discussion of the essence of perturbations. Although the model is meant to shed light on the processes in an economic system in the wake of a calamity, the model operates as a usual equilibrium artefact, not accounting for the mismatches and imbalances in the economic network brought about by the major shocks.

Ghosh model provides a solution for the major drawback of conventional input-output model, which IO model is rigid and limited to demand driven type. Ghosh model provides flexibility to allow IO model to be supply driven. MDM model is a demand-driven model, but with exogenous supply constraints. MDM model, like many conventional input-output models, is rigid enough not to easily adopt supply constraints incurred endogenously during model stimulations.

2.6.5 IO modelling and other techniques

There are several quantitative methodology framework available in the literature. The comparison summary is shown below:

- Input-output model: Its main advantages are the possibility of managing with the interconnectedness among sectors, agents and regions make it compatible with engineering models. The information in the model take into consideration all the production inputs and is treated in value terms but is sensible to physical changes. The production technology is implicit in the model. Its characteristics make it suitable for risk analysis through the use of IO multipliers and can provide distributional analysis.
- Computable General Equilibrium (CGE):_Other methodology that has become greatly used in recent decades in this field is the CGE model. Some researchers see this model as an improvement to the IO model, mainly regarding with manageability of supply constraints, price changes, non-linearity, and flexibility in input and import substitutions and maintaining distributional considerations in the analysis. The CGE model also deals well with regional effects of an external shock. The treatability of behavioural changes allows the explicit consideration of resilience. The main weaknesses of the CGE model are related with the characteristics of natural disaster impacts. This model considers the economy in equilibrium in each step, while it has been argued that after a disaster, imbalances in the economy are

present and most of the time persistent. Additionally, the behaviour of agents is not always optimal in these situations.

- Econometric models: The main strengths are its rigorous statistical foundations, which make them suitable for forecasting. The time-series data used in these models allows for counterfactual analysis as well as uncertainty incorporation. Weakness is that data they use does not normally contain information on previous disasters.

3 Common approach in BASE

3.1 Introduction

In chapter 2 we have given an overview of upscaling approaches from literature, which are different for different sectors. In this chapter we expand on this by presenting a scheme for upscaling cost and benefits of adaptation. For this purpose in this section a methodological framework is presented to use for upscaling cost and benefit of climate change adaptation.

As formulated in deliverable 6.1 ultimately one of the main central questions of BASE is what the full costs and benefits are of adaptation in Europe. Underlying questions are:

- What part of major sectorial costs (investments and damages) can be attributed to adaptation?
- What is the optimal mix between investing in mitigation and adaptation?
- What are the economic advantages of one sort of strategy over the other in terms of:
    - o *Direct Economic Performance* – often this refers to direct costs and benefits (like avoided damage) of strategies.
    - o *Wider Economic Performance* – referring to cross-sectorial effects and economy wide effects. Benefits of adaptation can extend beyond the risk impact regions throughout the economic production and consumption supply chain.
    - o *Sustainability* To include potential environmental benefits that cannot directly be quantified in economic terms
    - o *Robustness/flexibility* – referring to the ability to deal with uncertainties. A strategy may perform well under one scenario (for instance RCP4.5) but poor under the other (for instance RCP8.5).

To ensure that the case studies yield as much as possible uniform information to answer these questions a set of specific case study questions was designed in D6.1 as a contribution to the case study protocol (D4.1). Key to successful conclusions from BASE is that they are not based on single case studies, but bare some power of expression from multiple cases. To give a few examples:

- To answer the question 'what share of costs of sectorial investments can be attributed to adaptation to climate change' it is necessary that the case studies similarly define a proper reference-strategy such that it includes all costs that would also be made without adaptation to climate.
- To answer question on direct economic performance it is important that the cases follow the economic evaluation protocol closely which is preferably sustained by the use of the PRIMATE tool.
- To answer questions on robustness and flexibility of adaptation strategy it is important that most cases define their strategies using the pathway approach and use the same wide range of scenarios (as prescribed by BASE)

In section 2.1 the terms qualitative accumulation, meta-analysis and adaptation modelling were introduced as upscaling methods. All three methods are part of the BASE approach. But not all case studies will contribute with a similar effort to each of them. Of course all case studies will come up with specific adaptation strategies employed in the cases. Most cases will follow up with estimates of cost and benefits either quantitative (CEA and CBA) or qualitative (MCA). A smaller group of cases will interact with the models in BASE and contribute to the improvement of these models. In addition conclusions on economics of adaptation resulting from BASE will built further on earlier studies and available data. This complex 'upscaling landscape' is depicted in Figure 3.1. The main conclusion from this figure (that although it is fictitious resembles the BASE sample size and numbers of sectors) is that due to the large number of sectors involved and the different focus of the cases the number of cases that really can be used per sector for a good quantitative meta-analysis is small.

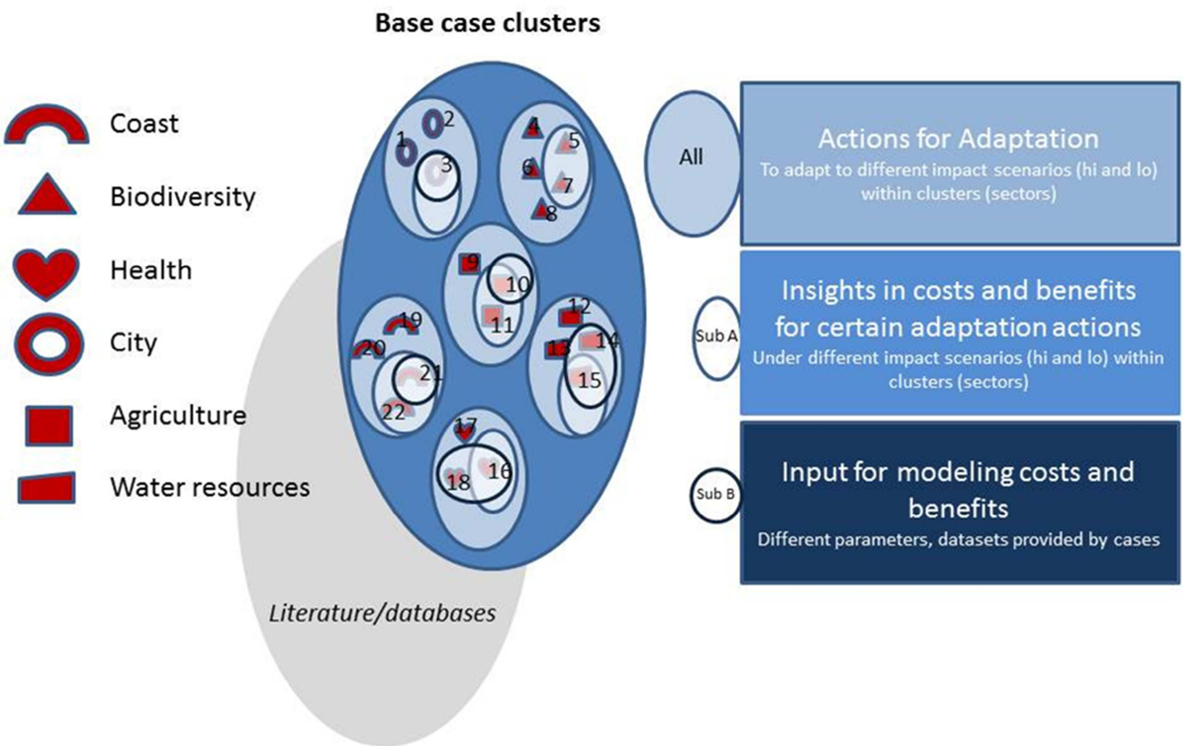


Figure 3.1 Schematic representation of upscaling of costs and benefits of adaptation within BASE. All case studies will come up with specific adaptation strategies (actions) employed in the cases. Most cases will follow up with estimates of cost and benefits either quantitative (CEA and CBA) or qualitative (MCA) (subgroup A). A smaller group of cases will interact with the models in BASE and contribute to the improvement of these models (subgroup B). In addition conclusions on economics of adaptation resulting from BASE will built further on earlier studies and available data. Key message is that despite the large number of cases the number of cases that really can be used per sector for quantitative analysis is small.

Therefore the expectation is that for a large part the upscaling exercise from case studies is of qualitative character. Of course there are different cross sections along which accumulation of results can be done as is indicated by textbox 3.1. The example presents a first analysis of the city cases in BASE and it shows that in most cases adaptation to the climate impacts heat waves and flooding due to heavy precipitation is one of the main challenges. In addition similar strategies across the case studies are proposed and evaluated. This will allow at least some good generalisation. On the other end of the scale is the case of improving the water supply system of the municipality of Cascais under increasing droughts.

How the meta-analysis and qualitative accumulation of BASE case studies will be executed is further elaborated in section 3.2.

The case study results in part can be used to also to compare with conclusions that result from the top down modelling exercises. In this way it will serve to validate the models. Besides that there will be all sorts of data generated within case studies that can be used to improve the input of top down models like for instance spatially diversified damage functions, protection levels etc. More detailed information on how models and case studies will cooperate within BASE to upscale information is presented in section 3.3.

To answer the question on what economy wide effects are of adaptation by reducing the risk due to extreme heat and flooding events one has to know how effects of those events cascade through the whole economy, from a small scale to a larger scale. This issue gets special attention within BASE, within a number of city cases. The extensive procedures set up for this is described in a separate chapter 4.

Textbox 3.1: Example ' upscalability' of city cases
The urban cluster consists of 7 case studies in which a diversity of impacts is expected and in some cases already experienced. The urban cases comprise of small cities Cascais (Portugal) and Jena (Germany), middle size cities like Venice (Italy), Rotterdam (Netherlands) and Leeds (UK) and large cities Copenhagen (Denmark) and Prague (Czech Republic).

Main Impacts
The city cases comprise at least 3 different climatic zones within Europe: Southern Europe (mainly dryer summers, heat waves), North/West Europe (mainly wetter winters), Central Europe (heat waves, increase of thunder storms in summer). There are 4 coastal cities involved that also have to deal with sea level rise. Two of them, Venice and Rotterdam, experience subsidence in addition.
The main impacts considered are:
- Increase of riverine flood risks (Rotterdam, Prague, Jena, Leeds)
- Increase of pluvial flood risks and insufficient drainage capacity (Copenhagen, Leeds, Jena, Rotterdam)
- Increase of flood risks due to storm surge (Venice, Copenhagen, Rotterdam)
- Decrease of fresh water availability for different sectors (Cascais)
- Urban heat Island effect (Cascais, Jena, Rotterdam)

Some trends and projected changes are more clear and persistent (Sea level rise, temperature, droughts in SE, rainfall in the UK) than others (rainfall patterns in CE). It is not clear in most cases yet what the current variability is the city should be able to cope with.

Main strategies considered
In dealing with *coastal and riverine flood* risks the cities consider similar strategies, which will make intercomparison interesting:
- Flood control through defences and barriers (Venice, Rotterdam, Prague)
- Early warning systems (Venice, Rotterdam)
- Flood proofing building and infrastructure (Venice, Copenhagen, Rotterdam, Leeds)
- Retention / room for rivers (Jena, Rotterdam, Leeds, Prague)

Reducing *heat stress* is also a common challenge among a number of cases by introducing a number of green and blue adaptation solutions (Leeds, Cascais, Rotterdam).
These strategies do also match well with strategies to cope with *intense rain events* also common in most of the cases. In addition to creating blue and green spaces, the design of more sustainable drainage systems is considered in a number of cases to adapt to increasing heavy precipitation events (Leeds, Jena).
Cascais is the only City case concentrating on *fresh water availability*, approaching it from 2- sides: increasing supply by improving the supply system, creating buffers and improving quality and decreasing demand by stimulating low water use. With respect to this impact it could better connect to other cases in other clusters. Cases vary from strong private contributions (Venice) to full public investments (Rotterdam, Prague).

Purpose of adaptation
There are a number of reasons given for the proposed adaptation strategies. In only few cases Climate change is the only driver for change. In addition:
- Autonomous subsidence and SLR
- Replacement of old drainage system
- Necessary maintance/renewal of flood defence system
- Necessary maintenance and renewal of the water supply system
- Retrofitting of infrastructure, built areas and buildings
- Increased demand for fresh water from increased tourism sector
- Increased asset values exposed to floods
- Better insight in current variability (1/500 flood Prague)

Also without climate change these 'drivers' would lead to necessary investments and costs. Investements that are (or should be) already part of sectoral investments agendas. Taking into account the projected climate change effects in the design will in some cases increase the costs of adaptation (higher defences). In some cases smart design may have co-benefits that outweigh the extra costs.

Evaluation procedure
All the cases involved are going to deliver some sort of cost benefit analysis for a large part expanding on existing studies and thus not necessarily using the new range of scenarios prescribed by BASE. Upcoming deliverable D5.2 will provide a better insight. Leeds, Rotterdam, Copenhagen cases will also apply IO-modelling for economy wide effects.

3.2 Lesson learned and best practice from economic evaluation of adaptation options in cases

Within BASE, workpackage 5 will provide case study outcomes on evaluation of case specific adaptation measures, including information on their costs and benefits. Deliverable 5.2 will collect the results of the case studies on economic evaluation but also describe the selected approach, data used etc..

Deliverable 5.5 will describe coherence within and among the case study clusters, These findings need to be critically reviewed in order to be able to draw more generalized lessons from them that can contribute to the BASE questions.

To be able to get closer to an answer to these questions 6.1 and 4.1 set up the protocol.

Based on this protocol case studies will deliver information on:

- Existing and future risks in the case studies
- Potential adaptation measures
- Evaluation approach applied (and why it is selected)
- Cost and benefit criteria considered (including units of measurement)
- Input data used
- Results of the evaluation of the different adaptation options
  - Ranking of options
  - Depending on evaluation method applied:
    - CBA: net present value, benefit-cost ratio, monetary costs and benefits
    - CEA: cost-effectiveness ratio, monetary costs, non-monetary level of target achievement
    - MCA: depending on the MCA approach: score etc., monetary and non-monetary figures on cost and benefit criteria
    - PCBA: non-monetary net present value scores, scores on the different benefit and cost criteria

For example, D5.2 will deliver two kind of information which can be beneficial on a larger scale:

1. Process guidance: Best practices and lessons learned for the process of economic evaluation:
   - When to choose which evaluation approach?
   - Which data sources are available?
   - How can different kinds of impacts be included in the economic evaluation?
   - As a result the “guidance for economic evaluation of adaptations” (D4.1, chapter 4) can be revised, improved and enriched by case study information and examples.
2. Overview and summary of case study outcomes:

- Transferability of such quantitative outputs will be relatively limited, as e.g. net present value figures are always very content specific and depend on the case study specific baseline chosen.
- However, general trends in quantitative outcomes can be probably given, based on the synthesis of case study results:
  i. Which kind of adaptation option tend to be effective or efficient (under which conditions)
  ii. Ranges of costs and benefits for certain types of adaptation options

Table 3-1 shows exactly the protocol the cases are going to follow when collecting results on economic evaluation.

The exact output of case studies, however, cannot be foreseen on forehand as Task 5.2 is currently on-going. The following procedure was agreed on:

1. Providing case study protocol and using the protocol in the cases. This protocol will be transferred into the case study living document by the end of April (see tables A4 and A5 in appendix). Task 5.2 will guide the cases in what questions the cases are expected to answer and what methods to use.

2. Draft findings from case studies on economic evaluation will be provided end of April.

3. Checking and comparing experience and data that will be available for upscaling during two intermediate case study workshops (May and Aug/Sept.2013). This workshop should yield an overview of economic evaluation approaches conducted in the case studies and amount and quality of outcomes that will be available. The workshop will give the opportunity to steer later reporting of the cases. The case study living documents will be the principal source of information and be used to update and expand the evidence base from the cases. There are generally three general mile stones to be distinguished:

   - End of April: methodology of cases and which kind of outcomes of the economic evaluation they will deliver

   - End of May: the economic evaluation approaches have had their first applications within the cases. These intermediate results are presented and discussed in the May workshop. Considerable corrections to methods are still possible.

   - End of July: Draft end results from case studies are delivered to the Task 5.2 leaders (UFZ). UFZ will review case study contributions and provide feedback for final corrections. Based on case study contributions UFZ will provide a synhthesis of Task 5.2 results with regard to 1) process guidance for economic evaluation and 2) overview on case study quantitative outcomes. D5.2 will be delivered end of September 2014.

   - The draft end results will be presented and discussed during a workshop end of August/Beginning of September. Also some first comparisons with model results will be done. Only minor connections can be made in this phase to case study results.

4. Final collection of the results on the evaluation of measures via 5.1, 5.2, 5.5.

Table 3-1 Key questions for economic evaluation of adaptation options in the case studies and data requirements for upscaling

Key questions	Auxiliary questions	For retrospective CS	For smaller, descriptive CS	For bigger prospective CS
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?	Please describe the risk situation before adaptation measures were implemented.	Qualitative description (if possible also quantitative)	Quantitative description, if possible monetary risks, maps
	Which assets and sectors are at risk under current climate variability?	=	=	=
	Which adaptation or protection measures are already in place? (refer to typology of measures in D6.1, table 2)	=	=	=
	How do these risks presumably change due to climate and socio-economic change? What are the main drivers, impacts and affected sectors (refer to BASE impact and sector categories, see also Table 1 of D6.1)	Which changes in risk were expected?	Qualitative description (if possible also quantitative)	Quantitative description, if possible monetary risks, maps
	Which climate and socio-economic scenarios?	Which CC and socio-economic scenarios have been used to estimate future changes in risk? How do they differ or relate to the AR5 scenarios?	If available please use downscaled data by CMCC on new IPCC AR5 climate scenarios () and socio-economic scenarios	If available please use downscaled data by CMCC on new IPCC AR5 climate scenarios () and socio-economic scenarios
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) Refer to otherwise expand on Table 3 of D6.1			

	When (roughly) will these critical levels be reached due to climate change or socio-economic change Give appropriate period (2015-2030,2030-2050, after 2050) for each considered combination of climate and socio-economic scenario.			
Step 2 Identification of adaptation measures and adaptation pathways				
What are the alternative adaptation measures?	What are the primary and secondary objectives of adaptation?	What was the objective?	What are the primary and secondary objectives of adaptation?	=
	What are potential measures to meet these objectives? (refer to typology of measures in D6.1, table 2)	Which alternative options have been compared?	What are potential measures to meet these objectives?	=
	What is your baseline option (the "business-as-usual"-option)? • What is the ambition level of this baseline strategy?: Maintaining current risk levels or current protection levels (implying with CC risks may increase)? • Is current backlog of investments for adaptation measures included or excluded? • Does it include only planned adaptation or also autonomous, non-planned adaptation?	Which was the baseline option?	Describe the "business-as-usual"-option	=
	Are there complementary measures? Is it appropriate to bundle these measures?	Have measures been bundled or has such a bundling been considered?	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	Have pathways of adaptation been considered?	If possible, describe potential pathways at least in a qualitative way	What is the "sell-by"-date of the measures or bundles of

	climate change – not any longer be able to meet the defined objectives?			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)? (see D4.1, chapter 4 for examples)	Which evaluation criteria have been considered to select adaptation options? (costs, benefits, economic social, environmental criteria?)	Try to consider at least the most important cost and benefit criteria	Try to consider all relevant criteria (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?	In which units were these criteria measured?	Please measure the performance of the adaptation options at least in qualitative terms (if possible in quantitative or monetary terms).	Please try to measure the performance of the adaptation options in quantitative and if possible monetary 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? (→ cost-benefit analysis)	Which evaluation method was used? (CBA, CEA, MCA, other?)	CEA or MCA (or partial CBA)	CBA, CEA or MCA
	Is it possible to express the positive effect (objective) by a single non-monetary indicator? (→ cost-effectiveness analysis)			
	Are there several relevant criteria which cannot or cannot easily be expressed in monetary terms? (→ multi-criteria analysis)			
Step 3c Weighting of evaluation criteria (applicable only to multi-criteria analysis)				
What are the preferences of stakeholders regarding	Are there different stakeholder groups with varying preferences	If MCA was applied: how has the weight	Try to elicit the preferences for the various criteria at	Try to include weights for different

the different evaluation criteria?	regarding the evaluation criteria?	elicitation been done? (stakeholders involved? weighting approach?)	least from the most important decision maker.	stakeholder groups.
	Which weight do stakeholders and/or decision makers attach to a substantial change in the performance of the adaptation options regarding each evaluation criterion? (→ Swing-Weight method)		=	=
Step 4 Data collection				
What are the costs of the alternative adaptation options? What are the benefits of the alternative adaptation options?	For each cost and benefit criteria selected in step 3a: What potential data sources are available, including damage & impact assessment methods or existing CBA studies on adaptation measures?	Which data sources have been used to assess the performance of the different adaptation options with regard to the criteria?	Use existing quantitative and monetary data…	Try to gather as much monetary and quantitative data as possible. Are model results from WP3 models available for your case?
	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?		…otherwise make use of expert knowledge.	If for some criteria no quantitative data is available, use expert judgement.
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)? Is it a linear discount rate or any other type (i.e. declining, hyperbolic, etc.) (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%)).)	Which discount rate was used to discount future values?	Which discount rate is recommended by national guidelines for climate change adaptation measures (or public investments)?	Which discount rate is recommended by national guidelines for climate change adaptation measures (or public investments)? (In addition, for testing the sensitivity of the results with regard to the different 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 regarding certain	Have uncertainties in the input data been taken into	Please describe uncertainties at least by a range of	Can uncertainties related to the performance of the

	evaluation criteria be described by a range (min-max), a triangular distribution (min, most likely, max) or any other kind of probability distribution?	account? How?	input data.	measures regarding certain evaluation criteria be described by a range (min-max), a triangular distribution (min, most likely, max) or any other kind of probability distribution?
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 (discounted benefits – discounted costs) of the alternative options? What is the benefit-cost ratio?	Results of the evaluation method applied? Please describe also intermediate results.	Depending on method chosen (in step 3) Please describe also intermediate results of the chosen approach.	Depending on method chosen (in step 3) Please describe also intermediate results of the chosen approach.
	For cost effectiveness analysis: Which alternative achieves a defined objective at lowest costs? What is the cost-effectiveness ratio?			
	For multi-criteria analysis: Which adaptation option performs best? (e.g. for PROMETHEE approach: which option has the highest net flow?)			
	What are the uncertainties associated with the performance of the different options? Is there and, if so, to what extent uncertainty in the ranking of options? 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)?	Are there uncertainties in the results? If yes, which uncertainties have been documented?	What are the uncertainties associated with the performance of the different options? Is there and, if so, to what extent uncertainty in the ranking of options?	What are the uncertainties associated with the performance of the different options? Is there and, if so, to what extent uncertainty in the ranking of options? 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)?

3.3 Upscaling through modelling

3.3.1 Introduction

In this section the upscaling through modelling is discussed. How are model parameters improved by using ground data and how are model outputs improved by using lower scale higher resolution results for calibration. For each model used in BASE the use of case studies for this purpose is discussed in **Error! Reference source not found.** to **Error! Reference source not found.**. In **Error! Reference source not found.** in the last column it is summarized to what model the case is contributing.

3.3.2 Upscaling adaptation gaps and needs in European agriculture

BASE takes a modelling approach to up-scaling impacts of climate change on agricultural production and needed adaptation responses and combines this with input from case studies in terms of information of local farm systems, experiences in autonomous adaptation, and perceptions of risks and vulnerability.

Crop productivity component of the SAMAR framework – simulating the range of conditions under which crops are grown:

Covering wheat, maize and soy beans, the Climate-Crop model is a process-based crop model that simulates the range of conditions under which crops are grown. The model focuses on a regional analysis of crop productivity rather than on the performance of individual crops, which is useful for defining adaptation needs at a regional level. Climate-Crop uses statistical models of productivity response to assess the sensitivity and adaptation to climate across nine agro-climatic regions in Europe. For each of the nine agro-climatic regions, a statistical model is estimated and used for up-scaling the response in agricultural productivity to changes in: i) temperature in most climate significant growth months; ii) annual temperature; and iii) water availability from precipitation and irrigation. The statistical models have been validated and calibrated to the nine regions in previous studies and are then applied to 247 agricultural sites across Europe as a spatial analysis of crop yield response to climate change. Relative changes in crop productivity and variation in the inter-annual variability of productivity are calculated based on the statistical models and data from the 247 sites under a reference scenario and a climate change scenario. Anomalies in the distribution functions under climate change compared to the reference scenario determine the level of impact and the risk on crop productivity. Impacts and risks are then used as the basis for assessing adaptation needs, based on the degree of vulnerability that characterises the different agro-climatic regions. Results from the 247 sites will subsequently be interpolated at the national scale in Europe to arrive at national results. In relation to interpolation: We need to describe here in more detail how the interpolations to country scale will take place.

Case studies will not need to provide input to the crop productivity model. The model itself is an upscale from field level to European/global scale.

However, case studies are expected to evaluate the relevance of the productivity output for their case area for both the baseline and climate scenarios:

- Each agricultural case study tests whether the baseline in the climate crop model in terms of yield per ha and type of yield is representative for their region/country
- Validate/examine whether the future crop productivity changes under climate change scenarios appear realistic for the case study region/country – assuming information of yield/ha, T and PP can be provided from the nearest of the 247 sites. This can for instance be done by asking agricultural experts in the region/case study stakeholders.

Agricultural water demand component of the SAMAR framework – assessing crop production responses to water availability:

Based on initial estimates of elasticities of yield to water availability, derived from the application of the crop productivity model above, BASE modify the yield-water elasticities to account for limitations in irrigation infrastructure, technology, management and value of irrigated production. The current water availability model focuses on the northern Mediterranean countries (Albania, Croatia, France, Greece, Italy, and Spain) and includes seven types of crops (wheat; cereals; rice; vegetables & fruit; oilseeds; sugar; and other crops). The water elasticities by country and crop class will be translated into changes in agricultural productivity by crop.

Case studies will not need to provide input to the water demand model. The model itself is an upscale from field level to European/global scale.

Adaptation choices component of the SAMAR framework - assessing regional choices of adaptation

The current version focuses on adaptation choices and adaptation needs in relation to reduced water availability (i.e. irrigated agriculture) and agro-chemical management. It does not (yet) include adaptation choice in cases of increasing water availability (excessive amounts of rain and flooding of fields). The core of this component is to compare the difference between optimal crop yield and adapted yields. Optimal yields are levels where there is no water limitation, optimal use of fertiliser, agro-chemicals and with no management constraints. Adapted yields are considered current yields.

Input from case studies to this component will be in the form of i) defining adaptation actions taken by farmers today (if any) [characterisation of action input]; ii) perceived costs of adaptation actions [quantitative data input]; iii)perceived benefits of adaptation actions [quantitative data input].

The analysis will make use of the agricultural case studies of BASE: Alentejo, Moravian, Ústi, Danish rural and the Iberian peninsula.

Adaptation Capacity Index (ACI) of the SAMAR framework – assessing how able farmers are to adapt to changes

BASE develops an adaptive capacity index (ACI) in order to define the extent to which the impacts of climate change and their interactions with social systems increase levels of vulnerability of agricultural systems (See Section 5.8 of Deliverable 3.2). The index aims at approximating the potential adaptive capacity of a country or region to future perturbations where a higher score indicates a greater ability to cope with and modify future climate impacts. The five elements of the ACI comprise i) social capacity; ii) economic capacity; iii) technological eco-efficiency; iv) natural capital; and v) climate capital.

This component of the SAMAR framework takes into account farmer perceptions of risks, needs for action, motivations and capacities that is generated in the case studies.

BASE aims at developing a common ACI across Europe that in quantitative terms can indicate areas of risks and vulnerability.

It is expected that the ACI will be partly developed based on participation with farmers in the agricultural cases, i.e. all agricultural case studies are expected to:

i) Provide input on the dimensions and elements relevant for the agricultural sector

ii) Subsequently provide data on the elements of the ACI such that BASE can provide a case specific ACI

3.3.3 Flood risks

With this modelling activity we will assess changes in flood impacts under different climate change projections, scenarios of socio-economic change, and multiple adaptation pathways. Flood impact metrics will include direct economic losses from damages to physical assets, number of people affected and other metrics (see Deliverable D3.1). We will incorporate local adaptation measures selected in the case-studies. The output will be flood damage estimates (aggregate numbers by river basin, country, or spatial data). Also, estimates will be made of additional flood damages due to changes in the flood hazard in response to climate change, and due to projected changes in exposure and vulnerability. In addition, estimates will be made of the required adaptation measures (construction of dikes and retention areas to prevent flooding, and adapted building to reduce impacts). The cost numbers on flood damages and adaptation costs can be aggregated to one economic loss value for northern and one value for southern Europe as requested by Ad-Witch.

Data needs from the case studies

Up-scaling of flood risk adaptation will consist of modelling of adaptation measures at the European scale that are informed by the case studies. A number of case studies in the BASE project that also quantitatively assess flood risk are being approached for a number of different types of information. More specifically, input is being sought from the following case studies:

- Ebro (Spain)
- Kalajoki (Finland)
- Saale (Germany)

- Tagus (Portugal)

However, any case study that addresses river flood risk, and assesses information on adaptation measures can provide information to the European scale assessment. The proposed adaptation approaches in these case studies however need to fall within on the following three broad categories:

- Flood prevention (structural measures, in particular dikes);
- Flood retention areas (buffering of flood water);
- Adapted building, reducing impacts and damages when floods occur.

The data needs regarding *adaptation* are the following:

- Overview of local adaptation pathways and individual adaptation measures proposed by stakeholders;
- Information on current flood prevention and dike systems, including information on protection levels (return periods for which protection is secured through these dike systems);
- Information (location, size, capacity) on current and/or planned (natural) retention areas within the case study area or river basin;
- Information on building vulnerability, and possible adaptation approaches proposed by stakeholders for adjusting buildings to reduce flood vulnerabilities.
- Estimated economic flood loss for current climate and future climate, and for different adaptation strategies for the case study area (if possible from work by the BASE research team, stakeholders, or other research organisations and projects;
- Reference period, scenarios and time-horizon considered in the flood loss estimates (mentioned above);
- Estimated implementation costs of the proposed adaptation measures;

Other data needs consist of information from case study areas where previously (or in current work for BASE) flood risks are being assessed using quantitative models. Bottom-up information from these case studies can be used to calibrate and assess the quality of the estimates by the European flood risk model. Types of information on *current flood risks* include:

- Where available: flood hazard maps; for different return periods (50, 100, 200, 500 years) inundation depths;
- Land-use maps, and maps of vulnerable objects within the case study areas (used in the flood risk model to calculate damages for different land-use types; such as urban areas, commercial, industrial, agriculture, infrastructure and so on).

Note that the European flood risk model can only accurately assess flood risks (for current time periods and future projections) for relatively *large* river basins, given the simplifications of the modelling approach, and large uncertainty in the meteorological input for present and future climates.

3.3.4 Health

The health cases defined in Spain and UK (Exeter and Madrid) cover in principle all measures for adaptation like: water and sanitation programs, warning systems, medical treatment and hospitalization, surveillance, evacuation plans, first aid.

For EU level in AD-Witch, aggregated adaptation costs are expressed as changes in health expenditure (absolute or GDP%) in some specified years and for different temperature increases (at least 2 or 3), + effectiveness (damage reduction as a % change in mortality and/or morbidity).

Adaptation costs are available from different sources for different temporal and geographical coverage, and climate scenarios, not necessarily compatible with AD-WITCH. Some kind of homogenization is needed before they can be used. The up-scaling will therefore require new assessment of existing data based on information about risk under CC, unit costs of main adaptation measures, assumptions about population growth and coverage.

3.3.5 Ecosystem services

3.3.5.1 InVEST ecosystem services modelling framework

InVEST allows modelling of impacts of climate change on ecosystem services by analysing scenarios that combine land use and land cover data (LULC) with climate projections. Therefore, InVEST modelling tool can be applied to model the climate change impacts on ecosystem services, delivery of ecosystem services in biophysical as well as economic terms.

3.3.5.2 InVEST modelling on the case study and European level

Within the modelling framework, InVEST will be applied to upscale the values of ecosystem services in order to model selected regulating services on the case study level as well as European level.

On the case study level, the Green Roof case is focusing on the provision of regulating ecosystem services in the Šumava National Park, Czech Republic, under various adaptation scenarios developed together with the stakeholders. These adaptation scenarios will include prospective land use changes integrating an adaptation and climate component that lead to changes in the provision of regulating ecosystem services as the side effect. Therefore, InVEST modelling tools will be utilized to assess the biophysical and economic value of regulating ecosystem services within the Green Roof case study.

On the EU level, the InVEST modelling approach will be applied to European-wide modelling based on the availability of LULC scenarios that that reflect climate change and adaptation on the European level. Currently, the selection of appropriate European-wide LULC scenarios is underway.

3.3.5.3 InVEST economic valuation modules

Detailed description of the specific InVEST modelling procedures is provided by deliverable D3.2, chapter on ecosystem services. This section aims to present approaches to the economic valuation of particular ecosystem service InVEST models based on Tallis et al., 2011.

Valuation of carbon sequestration

Economic value of carbon sequestration is estimated by the valuation model as a function of the amount of carbon sequestered, the monetary value of each unit of carbon, a monetary discount rate, and the change in the value of carbon sequestration over time. The discount rates include standard financial discounting as well as adjustments of the social value of carbon sequestration over time. The model simplification is in the assumption of linear change in carbon sequestration over time, opposite to the natural nonlinear path. This might lead to undervaluation of the amount of carbon sequestered (Tallis et al., 2011).

Valuation of water purification: Nutrient retention

The water purification valuation model use water treatment costs and a discount rate to determine the value of water purification contributed by the natural system. The valuation model does not address chemical or biological interactions besides filtration by terrestrial vegetation (e.g. in-stream process) (Tallis et al., 2011).

Valuation of sediment retention

Valuation of sediment model is based on the avoided cost of dredging and/or water quality treatment. To determine the economic value, the cost of sediment removal is assigned by the user.

The following equation determines the value each sub-watershed contributes to reservoir maintenance by helping to avoid erosion (Tallis et al., 2011).:

$$sed\_Value_s = Costs(s) \text{ x } sret\_sm \text{ x } \sum_{t=0}^{T-1} \frac{1}{(1+r)^t}$$

sed_Value_s is the present value of sediment retention on subwatershed *s* over *T* years, where *T* indicates the period of time over which the LULC pattern is constant (for water quality valuation) or the length of the reservoir life (for dredging valuation), *sret_sm* is the total sediment retention adjusted either for dredging (*sret_sm_dr*) or water quality (*sret_sm_wq*), *Cost(s)* is the marginal cost of sediment removal for either the service of dredging or water quality treatment and *r* is the discount rate. The *Cost(s)* may vary across reservoirs or water treatment facilities if different technologies are employed for sediment removal. If this is the case, the user may input reservoir- or plant-specific removal costs. The marginal cost of sediment removal should be measured in units of monetary currency per cubic meter.

3.3.5.4 InVEST data needs

InVEST tools allow for the modelling of an array of regulating ecosystem services on various spatial scales. Therefore, InVEST tools are especially suitable for both local case studies and Europe-wide assessment within the BASE project. Two types of regulating ecosystem services will be assessed on the Europe-wide level – carbon storage and nutrient retention, modelled by corresponding InVEST tools. Within the Green Roof case study, an additional ecosystem service of sediment retention will be modelled.

The basic data inputs, common for all the above mentioned tools, are current land use maps and future LULC scenarios. Current LULC maps in a sufficient resolution are available in the form of CORINE Land Cover data sets. The selection of appropriate European-wide LULC scenarios is now underway. On the local scale, future scenarios will be developed using ArcGIS based on the collaboration with local stakeholders.

Subsequent data needs depend on the individual models utilized (see following Tables). In general, various ecological and socio-economic parameters of the study location, mainly in the form of raster maps and table databases, are required. The data will be gained from European and localized studies, literature review.

Table 3-2: Data needs for the Carbon Storage and Sequestration model

Data type	**Unit of measurement**	**Data format**	**Data sources: Green Roof case study**	**European modelling**
Current LULC maps	–	ESRI GRID	CORINE Land Cover 2013	CORINE Land Cover 2013
Future LULC maps	–	ESRI GRID	Future scenarios (scenario workshop)	To be decided
Carbon pools: Aboveground biomass, belowground biomass, soil carbon, dead	[Mg ha^{-1}]	*.dbf	Literature review and local data (e.g. CzechTerra project)	Literature review

organic matter				
The value of sequestered ton of carbon	[€ Mg^{-1}]	–	Tol, 2009	Literature review

Table 3-3: Data needs for the Water Purification: Nutrient Retention model

Data type	**Unit of measurement**	**Data format**	**Data sources: Green Roof case study**	**European modelling**
Current LULC maps	–	ESRI GRID	CORINE Land Cover 2013	CORINE Land Cover 2013
Future LULC maps	–	ESRI GRID	Future scenarios	To be decided
Digital elevation model	–	ESRI GRID	Czech Office for Surveying, Mapping and Cadastre	ASTER global digital elevation model
Soil depth	Mm	ESRI GRID	European Soil Database, European Commission – JRC	European Soil Database, European Commission – JRC
Average annual precipitation	Mm	ESRI GRID	CMCC	CMCC
Average annual potential evapotranspiration	Mm	ESRI GRID	CMCC	CMCC
Maximum root depth for vegetated LULC classes	Mm	*.dbf	Literature review	Literature review
Evapotranspiration coefficients for each LULC class (to modify potential evapotranspiration)	%	*.dbf	CZEG	Literature review
Watersheds and sub-watersheds	–	Polygon shapefile	T. G. Masaryk Water Research Institute	To be decide (EEA)
Nutrient loading (export) coefficients for each LULC class	[g ha^{-1} yr^{-1}]	*.dbf	Literature review	Literature review

Efficiency of nutrient removal by vegetation for each LULC class	%	*.dbf	Literature review	Literature review
Annual cost of nutrient removal treatment	[€ kg^{-1}]	–	Vačkář et al., 2010	Literature review

The Water Quality InVEST model requires more data sources, since a number of climate and soil parameters need to be specified (see Table 3-3). On both the case-study and European levels, climate and soil data will be derived from Europe-wide sources, the European Soil Database provided by JRC and climatic scenarios provided by CMCC within the BASE project. Additional parameters, e.g. root depths or nutrient loading coefficients, can be obtained from literature review and will be uniform for both the Green Roof case study and European modelling.

Similarly as in the case of carbon sequestration, the economic value of retained nutrients presents the benefit side of adaptation scenarios.

Table 3-4: Data needs for the Sediment Retention Model: Avoided dredging and water quality regulation model

Data type	**Unit of measurement**	**Data format**	**Data sources: example for the Green Roof case study**
Current LULC maps	–	ESRI GRID	CORINE Land Cover 2013
Future LULC maps	–	ESRI GRID	Future scenarios
Digital elevation model	–	ESRI GRID	Czech Office for Surveying, Mapping and Cadastre
Rainfall erosivity index (R)	[MJ mm (ha h $yr)^{-1}$]	ESRI GRID	Janeček et al., 2012
Soil erodibility (K)	[t ha h (ha MJ $mm)^{-1}$]	ESRI GRID	CZEG
Watersheds and sub-watersheds	–	Polygon shapefile	T. G. Masaryk Water Research Institute
Cover and management factor for each LULC class (C)	–	*.dbf	Literature review
Management practice factor for each LULC class (P)	–	*.dbf	Literature review

Efficiency of sediment retention by vegetation for each LULC class	%	*.dbf	CZEG
Cost of sediment dredging	[€ m^{-3}]	*.dbf	CZEG
Cost of sediment for water quality	[€ m^{-3}]	*.dbf	CZEG

The ecosystem service of sediment retention will be evaluated only for the Green Roof case study, since it requires fine-scale elevation data, which cannot be processed for the spatial extent of the whole Europe. As this InVEST modelling tool is based on the USLE equation, assessing the avoided erosion, all the required data represent parameters incorporated in this equation, i.e. slope characteristics, rainfall erosivity, soil erodibility and cover and management practice factors. Therefore, localized data from studies will be utilized as sources for individual parameters.

4 Adaptive input-output modelling and its application to case study cities

This chapter will describe the development of an adaptive input-output model to estimate the total upscaled economic effects (i.e. cascading economic effects of adaptation of climate extremes through production supply chains). In particular, we will apply the same methodology to estimate the direct and indirect costs and benefits in mitigating flooding events in three case cities – Leeds, Rotterdam and Copenhagen.

Chapter 4.1 describes the modelling procedures of ARIO analysis. Chapter 4.2 details the methodological techniques in ARIO analysis. Chapter 4.3 records data requirements for three case cities in applying ARIO model to estimate the total upscaled economics impact.

4.1 Adaptive Regional input-output (ARIO) modelling procedures

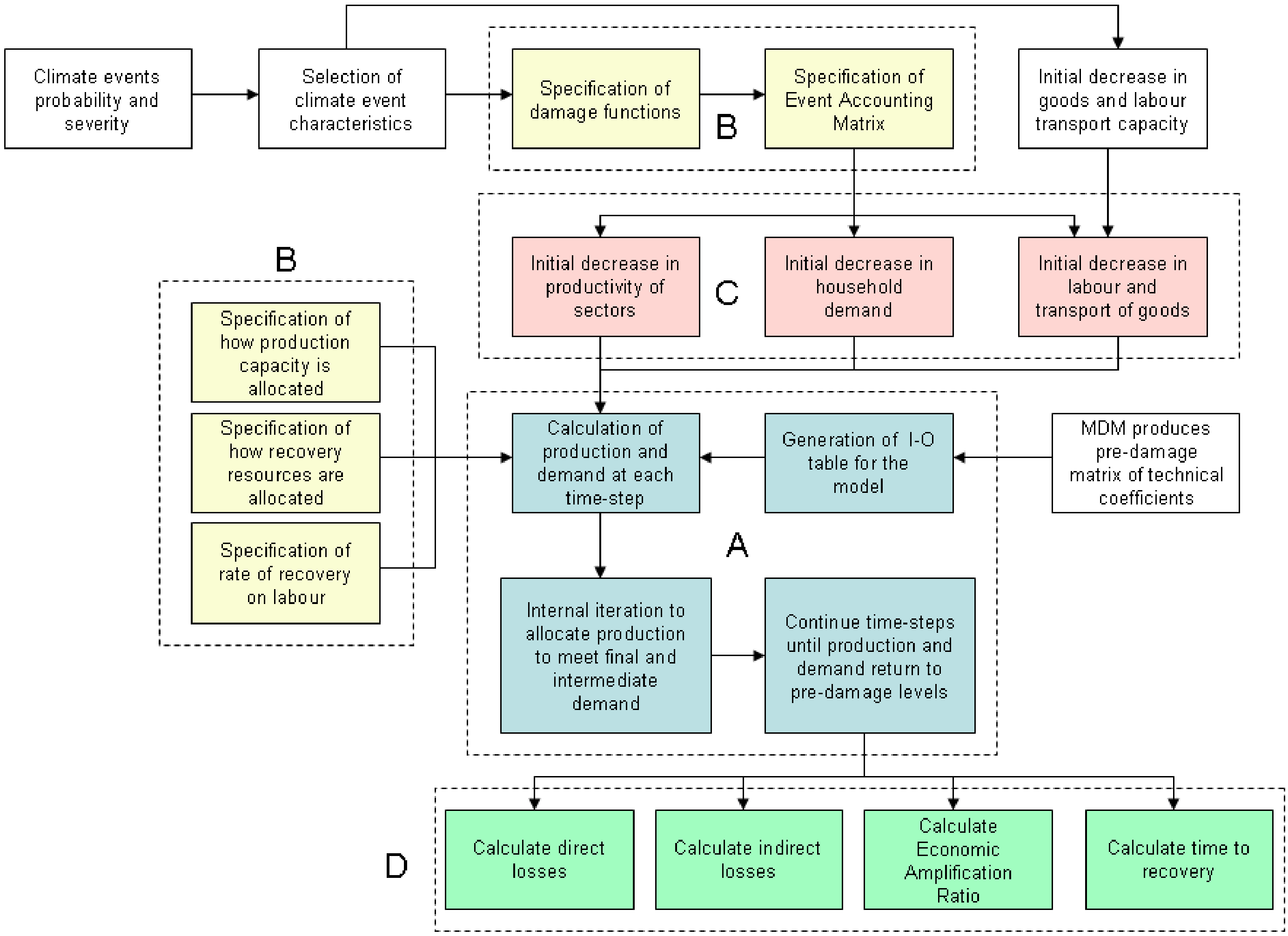
An ARIO model will be developed for the purpose of BASE project to estimate the cascading effects to wider economies due to adaptation / mitigation to local flooding event. The previous versions of ARIO model have been used to assess the effects of Hurricane Katrina on the economy of Louisiana (Hallegatte, 2008); to assess terrestrial flood risk under future climate change in London (Li et al., 2013).

The flow of calculations is shown in Figure 1. In that figure, the following apply:

- The blue boxes inside the dashed box labelled A is the ARIO model itself. It performs all calculations of the recovery of case study cities after a flooding event.
- The yellow boxes labelled B are specified exogenously by the user based on (i) the damage functions, (ii) the loss of transport capacity (can be modelled exogenously by transport models if available) and (iii) decision rules concerning the allocation of recovery resources and production capacity (these can be varied by the user).
- Item (i) is determined entirely by the damage functions.
- Item (ii) determines the loss of labour and the loss of capacity to transport goods (including exports and imports) – and their recovery – following the initial damage. The user can specify the relationship between loss of transport capacity and loss of labour and/or flow of goods, but this specification is exogenous to the model based on empirical studies of how these relationships take place.
- Item (iii) concerns the rules by which limited resources are allocated out after an initial damaging event. These rules consider (a) how production capacity, as it rebuilds, is allocated out to satisfying final demand or intermediate goods production; it is assumed that demand for intermediate goods is satisfied first, followed by demand for final goods, but the user can vary this assumption; (b) how capital resources such as finance are allocated to recovery; again the user can vary this assumption by operating the model in two modes: one where production capacity builds by the exogenously specified rate mentioned previously and one where production capacity has full priority in the allocation of resources (this significantly shortens the recovery period, albeit perhaps at the expense of GDP during that recovery); and (c) how labour and the flow of goods recovers as the transport system is repaired.

- The red boxes labelled C specify the Event Accounting Matrix (EAM) that specifies quantitatively how the initial damage from flooding event affects the production capacity and demand in the model. This specification is exogenous to the ARIO model. The EAM consists of a collection of damage functions.
- The green boxes labelled D are the outputs of the model. The most significant outputs are temporal graphs of the (i) Direct Losses, (ii) Indirect Losses, (iii) the ratio of Indirect Losses to Direct Losses, from which one can calculate an Economic Amplification Ratio, and (iv) the time recovery of the economy, which is a measure of resilience of an economy. To explore the issue of vulnerability, the model is operated by replacing the EAM with a matrix in which only one economic sector at a time is reduced in production capacity, and the recovery period, Direct Losses and Indirect Losses calculated over the period of recovery. By repeating this process over all sectors one at a time, the user can determine which sectors make the economy most vulnerable to indirect losses.

Figure 4.1 The flow of information and calculations within - or exogenous to - ARIO model.



Source: Crawford-Brown et al., 2013

4.2 Methodological details for ARIO model

The ARIO modelling generally involves 8 modelling steps.

Step 1: Specify the nature of the flood event according to the natural characters of case study cities. This step is carried out completely exogenous to the ARIO model.

Step 2: Specify the initial physical damage to assets, health, services (e.g. transport), etc resulting from this extreme weather. This must include damage to buildings (both commercial and household), infrastructure and health, and specify how this damage affects production capacity, labour availability, transport of people and goods (including imports and exports), and demand for final goods by households. This step should be carried out by flood modellers and hydrologists in BASE, working with the economics team to ensure characterisation of initial damage is related clearly to economic activities appearing in the ARIO model.

Step 3: This physical damage from Step 2 is converted into economic terms (e.g. from number of buildings flooded for number of days to amount of assets loss in monetary unit). The process of conversion to economic units is performed through the development of Damage Functions for each sector of the economy. The damage is in regard to production capacity in each sector and demand for final goods in the household. The units here are monetary, and are the same as those used in the calculation of GDP (£/month, as one month is the time step of the model as described later). This step is carried out by the economics team.

Step 4: The heart of the ARCADIA-ARIO model is a production-demand equation, shown as:

$$\mathbf{x} = \mathbf{A}\mathbf{x} + \mathbf{f} \qquad (1)$$

where **x** represents sectoral production output, **f** represents final demand and **A** is the technical coefficient, where a coefficient a_{ij} refers to the amount of input from a sector *i* required by the sector *j* for each unit of output. The term **f** consists of household consumption (f_{hh}), governmental expenditures (f_{gov}), capital formations (f_{cap}) including recovery of stock, exports (f_{exp}) less imports (f_{imp}), and reconstruction-driven demand, as shown in Equation 2:

$$\mathbf{x}(i) = \sum_j \mathbf{A}(i,j)\mathbf{x}(i) + \begin{cases} \mathbf{f_{hh}}(i) \\ \mathbf{f_{gov}}(i) \\ \mathbf{f_{cap}}(i) \\ \mathbf{f_{exp}}(i) \end{cases} - \mathbf{f_{imp}} \qquad (2)$$

Step 4 requires the matrix of technical coefficients, which is the foundational I-O matrix. This matrix is obtained regional input-output table. This matrix is then placed within ARIO for use in all time steps. Note that this approach assumes the structure of the economy remains invariant after a damaging event, with the exception of changes specified in the EAM; only the monetary flows between the economic sectors within this structure change as the economy recovers. There is also, therefore, the assumption that the economy returns in the end to its original structure and flows after all damage has been repaired.

There are two variants of the model available for use in ARIO model. The first variant uses the assumption above: that recovery brings the economy back to its initial condition. The second variant recognises that during the time of recovery, there would have been economic change (e.g. growth of GDP) if the damage had not occurred. In this variant, the recovery places the economy back onto the trajectory of growth that would have taken place had the damage not occurred.

Step 5: Specify the constraints on economic recovery, and how these change over time during the period of recovery. These constraints are divided into (i) labour, (ii) capital and (iii) final demand from the household sector.

(i) Labour constraints are related primarily to damage to the transport system, where the constraint is related to both transport damage (e.g. buckling of railway lines) and human health impacts. This constraint on labour is provided exogenously to the model, as these are factors related to infrastructure and health, and not to the economic system. They are captured in the part of the Events Accounting Matrix (EAM) involving labour availability, with separate values provided for each monthly time step in consultation with the transport and human health experts (or relying on real data) in BASE.
Labour loss is introduced into the model as a constraint on production. In order to estimate the induced output loss by labour shortage (which in turn is related to interruption of transport as specified in the EAM), the amount of labour for sector *i* in the pre-disaster condition, $L_0(i)$, and the amount of labour still available to work (or able to travel to work) for industry *i* in the post-disaster period, $L_{rem}(i)$, are specified. This yields:

$$\mathbf{q}_{\mathbf{lab}}(i) = \frac{L_{\text{rem}}(\text{i})}{L_0(i)} x(i) \qquad (3)$$

(ii) Constraints on production capacity are a function of both the initial damage specified in the EAM (created from the Damage Function Step 3) and an exogenously-specified rate of investment in repair and replacement of this production capacity. Again, there are separate values for this constraint in each time step. The user specifies the fractional repair or replacement in each time step, again within the EAM.
In regard to capital constraints on the recovery of production capacity, we firstly investigate the relationship between productivity of capitals and value added in case city, captured in the term **k**(*i*). Secondly, we work out the remaining capital damage relative to the pre-disaster condition, defined by:

$$\boldsymbol{q}_{cap}(i) = \frac{1}{\boldsymbol{k}(i)}\left(\boldsymbol{f}_{cap}(i) - \boldsymbol{d}_{cap}(i)\right) \quad (4)$$

Here f is the capital prior to the damage and d is the loss of capital due to the damage. As mentioned above, the term *k* is the ratio of productivity of capital to value added in the case city economy. Equation 4 then defines the loss of value in the case city's economy following the damage to production capital.

(iii) Constraints on final demand within the household sector are related solely to luxury (non-basic) goods. Immediately following the extreme weather event, households will switch their consumption pattern to more basic goods and services. Consumption of luxury goods and services will be reduced. We assume that imports of basic goods and services are not constrained; i.e. that an economy will find a way, perhaps through significant government intervention and imports, to supply these. The basic goods and services whose final demands are not assumed to be affected by the damage include: food, water, clothing and health care. The consumption from utility industries such as electricity and gas is, however, subject to local availability (specific scenarios can be applied). For both demand of luxury goods and for energy supply, the recovery towards full capacity in the time steps is specified in the EAM by the user.

The constraint on production capacity in any time step is the minimum between labour shortage and capital shortage driving total outputs (i.e. the constraint on production capacity is whichever of these two is most constraining). The maximum possible production capacity in a time step is then equal to the minimum production capacity under the labour and capital constraints:

$$\mathbf{x}_{\mathbf{rem}}(i) = \mathrm{MIN}\left\{\mathbf{q}_{\mathbf{lab}}(i); \mathbf{q}_{\mathbf{cap}}(i)\right\} \quad (5)$$

Step 6: The model then follows the recovery of the economy (using Equation 1) in time steps of one month. During these iterations, the model calculates production capacity in each sector, intermediate demand (i.e. goods and services from one sector needed by a second sector to complete final production of goods), and final demand, including imports and exports. Iterations are required during a time step because of the allocation process described in Step 7. This process means that the extent of recovery in any time step is limited by the ability of the "weakest link" in the supply chain for intermediate demand. If local production exceeds local demand, exports can increase. If local demand exceeds local production, imports will increase. Both imports and exports may in turn be constrained by damage to the transport system; the default value is that they are unconstrained (i.e. that the initial damage constrains flow of people and goods within the city, but not between the city and outside economies because different transport options will be selected for this import-export flow).

Step 7: Specify how the limited production capacity is to be allocated out to intermediate and final goods during the period of recovery. This specification is a critical point at which the approaches of Hallegatte (2005, 2007, 2008) and Steenge and Bockarjova (2007) differ in developing their versions of the I-O models for post-disaster recovery. Steenge and Bockarjova argued that a disproportioned economy following a disaster will require an economic adjustment process to re-balance itself before it can grow further according to von Neumann balanced growth theory. The implication is that the disaster may change the flow of goods and services for some period of time, but a deeper structural change in the economy will not occur. They further argued that the economic recovery following a disaster happens in two steps: first the economy adjusts itself in terms of fixed (pre-disaster) industrial output apportionments with no change in the relative degree of activity in each sector. The economy will then grow again towards the level of economic output in pre-disaster condition, with all sectors growing proportionately at the same rate.
By contrast, the economic adjustment process is quite different in the approach of Hallegatte (2005, 2007, 2008). If an industry cannot satisfy total demand post-disaster, its production goes first to satisfying intermediate consumption from other industries. All industries are assumed equally rationed: what an industry gets is proportional to what it ordered pre-disaster. The rationing scheme of Step 7 used in the ARIO model is a mix of a priority system and proportional rationing, where the relative degree of economic activity in different sectors (compared against the pre-disaster activities) may change for some period of time. However the aim of the rationing scheme is usually to allow the economy to return to its pre-disaster condition, which then will be built on for further economic development. Each industrial sector is individually rationed to allow the economic production structure to return to the pre-disaster conditions. The main advantage of this approach is that it is built on strong economic development theory and always allows the economy to develop into the most economically efficient structure (believed to be that which was in place before the disaster).

When industry *i* has limited capacity insufficient to fulfil the full demand required by both intermediate and final consumption, the rationing scheme prioritises the destination of the commodity *i*. Priority is given to intermediate demand over final demand. This assumption is justified because relationships between businesses are usually deeper than those between businesses and primary consumers, and a business will favour business clients over household clients. In addition, it is likely that policy interventions will favour these same business to business relationships in order to ensure stability and most rapid recovery of the production chains. The model user can specify how this allocation process takes place within the economy.

Step 8: Specify how final demand is to be allocated out during recovery. Within final demand, we assume all categories will receive the commodity *i* (after it fulfils the intermediate demand) in equally proportional ways. For example, household demand satisfied after intermediate consumption will be:

$$f_{hh\_rem}(i) = f_{hh}(i)\,\frac{x_{rem}(i) - \sum_j A(i,j)x_{rem}(j)}{x(i) - \sum_j A(i,j)x(j)} \quad (6)$$

Additionally, demand increases in six sectors due to reconstruction of damage, with half of that increase within the Construction sector, and the remainder spread uniformly (e.g. assuming to be 10% each, which can be different according to case city) across the other five sectors (In all cases, direct losses are largely to household capital and to the following industrial components: Mech. Engineering, Electronics, Elec. Eng. & Instrum, Motor Vehicles, and Manuf. Nes).

Similarly, government demand satisfied after intermediate consumption is satisfied will be:

$$f_{gov\_rem}(i) = f_{gov}(i)\,\frac{x_{rem}(i) - \sum_j A(i,j)x_{rem}(j)}{x(i) - \sum_j A(i,j)x(j)} \quad (7)$$

Export satisfied after intermediate consumption is satisfied will be:

$$f_{exp\_rem}(i) = f_{exp}(i)\,\frac{x_{rem}(i) - \sum_j A(i,j)x_{rem}(j)}{x(i) - \sum_j A(i,j)x(j)} \quad (8)$$

Industrial reconstruction after intermediate consumption is satisfied will be:

$$d_{cap\_rem}(i) = d_{cap}(i)\,\frac{x_{rem}(i) - \sum_j A(i,j)x_{rem}(j)}{x(i) - \sum_j A(i,j)x(j)} \quad (9)$$

Household reconstruction demand after intermediate consumption is satisfied will be:

$$d_{hh\_rem}(i) = d_{hh}(i)\,\frac{x_{rem}(i) - \sum_j A(i,j)x_{rem}(j)}{x(i) - \sum_j A(i,j)x(j)} \quad (10)$$

These allocation relationships apply until total production has risen back to pre-disaster conditions.

Even with the above allocation of production capacity, a rationing scheme between intermediate industry consumers may still be necessary if damage is extensive. Each industry may be unable to produce enough either because its own production capacity is insufficient or because other industries are unable to provide the necessary amount of inputs in the production chain.

$$\sum_j \mathrm{A}(i,j)\mathrm{x_{rem}}(j)$$

The term represents the case where industry *i* is asked to satisfy needs of other industries. Then we consider the following two cases:

$$\mathrm{x_{rem}}(i) > \sum_j \mathrm{A}(i,j)\mathrm{x_{rem}}(j)$$

when the industry *i* is able to provide enough commodity to all other industries in the production chain and therefore the production of these other industries is not affected.

$$\mathrm{x_{rem}}(i) < \sum_j \mathrm{A}(i,j)\mathrm{x_{rem}}(j)$$

when the industry *i* is not able to provide enough commodity to all industries and so each industry *j* sees its production limited by the availability of commodity *i*. In that case, the production of the industry *j* is bounded by:

$$\mathrm{x_{rem}}(j) = \frac{\mathrm{x_{rem}}(i)}{\sum_j \mathrm{A}(i,j)\mathrm{x}(j)}\mathrm{x}(j)$$

Households or industries can also seek alternative suppliers from other regions via imports if local production cannot meet their demand in the post-disaster period. However there are no data or experimental studies on how households or companies react to production shortage by turning to external producers for short-term shortfalls due to disaster recovery. We assume that imports are always available at the required levels to supplement loss of productivity internal to the case city's economy, constrained only by whether those imports can be transported.

Step 8: Run the above iterations (within a time step) and then run successive time steps over the period of recovery until the pre-damage demand is met, and production equals this demand (which also means production had returned to pre-damage levels).

4.3 Data requirements for cast study cities

In BASE, we have selected three case study cities to apply the ARIO model to estimate direct and indirect economic costs and benefits in adapting or mitigating flooding to case study cities as well as the supply chain cascading effects to the national level.

4.3.1 A brief introduction of case study area

The *Leeds City Region* has a population of three million and an economy worth £52 billion a year. It is a fairly typical European city region in terms of its geography, building stock, transport system, economic composition and energy use. There is a significant commitment to both climate change mitigation and adaptation shown in part through the “City-Scale Mini Stern Review” carried out for the Centre for Climate Change Economics and Policy in SRI for the Leeds City Region Local Enterprise Partnership. In BASE we will consider the same region and work with the existing and new stakeholders to conduct a fundamental analysis of the issues of adaptation in the conceptual framework developed for BASE.

Copenhagen is the capital and most populous city of Denmark, with an urban population of 1.2 million and a metropolitan population of around 2 million. Over past years, Copenhagen has frequently suffered from climate change induced flooding. Copenhagen has been working on adaptation to climate change for many years for example through the municipality’s wastewater plans. These adaptations have been based on development in the climate that has already occurred. The accelerating trend in climate change made it possible to draw up a strategy based on projections for the climate of the future. The strategy is developed in the ‘Copenhagen Climate Adaptation Plan’ August 2011.

Rotterdam City is lying in the Western part of the Netherlands, on the borders of the river Rhine delta. The western part of the city, nearest to the North Sea covers one of the largest port areas in Europe. With about 600,000 inhabitants Rotterdam is the second largest city in the Netherlands. The city area contains 30 km of port area and 400 km of canals. Most of the urban area is built in polders with ground levels up to 7 meters below sea level. The City of Rotterdam recently developed a “Water vision 2030” that describes how the city plans to enhance its attractiveness as a water city, meanwhile protecting itself from the dangers of water, mainly floods. Three types of flooding threaten the city of Rotterdam: tidal surges from the North Sea, river floods on the river Rhine and pluvial floods in the densely built urban areas. All are expected to increase with climate change presenting a serious challenge to the protection of the city.

4.3.2 Flood scenarios development

We will closely work between BASE researchers and local stakeholders to develop future flood scenarios for each case city. Since each city has already published their own climate change adaptation plan (or equivalent document), we will sufficiently review any existing flooding scenarios which may be able to take as BASE scenarios. After flood scenarios are defined, BASE researchers will explore the estimation of direct flood damage by developing a set of damage functions based on various risk assessment models for each case study city. It’s necessary to verify the results with the stakeholders prior to conducting next step of estimation of propagated impacts to the wider economies. The indirect damage can be modelled by integrating the local economic datasets and direct damage datasets into the developed adaptive input-output model (as described above). In particular, the damage function would have the function to translate flood depth and velocity to impact regions into

- Industry capital loss – including infrastructure damage, building and production capital loss.
- Labour productivity and availability during and after the event.
- Residential capital loss – including houses and household appliances.

- Affected population – death and hospital visits and admissions.

4.3.3 Data requirement for city level input-output table

Indirect effects are effects experienced in another time and another place then the regions affected by the climate extremes (e.g. flooding). These effects can only be linked to climate extremes using economic modelling through regional input-output modelling approaches that model repercussions and cascading effects of the extremes throughout the spatial economic system. For that purpose, existing models ("on the shelf") will be used (see also task 1.1). We will use the combination of inter-regional hybrid IO model that integrates some adjustment mechanisms for demand and supply (see Annex with three scientific papers for more details) and the existing EU-wide SCGE model RAEM-Europe (see Annex for model description) for the calculation of indirect effects. The short and medium term indirect effects will be calculated using the IO approach whereas the long term effects will be calculated using flexible SCGE framework. The table below represent an overview of the methodological approach for the calculation of indirect effects.

Table 4.1 General overview of methodological approach for estimation of indirect economic effects

	Description	Level of details	Proposed methodological approach	Data needs
Indirect effects	Disruptions of economic activity and loss of human lives and health in the affected region(s)/city(is) have immediate effects on the consumers, up-stream and down-stream sectors in the same/other regions	NUTS 1 or NUTS2 regions whenever possible Sectoral details of EXIOBASE IO tables: 164 production sectors. Some more sectoral detailed can be added if necessary for a specific case study using the Life Cycle Inventory (LCI) data	Regional Adaptive Input-Output model that incorporates the representation of productive capacity and partial flexibility of economic system (some parts of final and intermediate demand adjust to the disruptions)	Multi-regional IO table for EU at NUTS1 or 2 level. Possible dataset can be World Input-Output model or RAEM-EU model IO table from EXIOBASE for 164 sectors/products City level economic account datasets (e.g. employment by industrial sector, value added by sector etc)

5 Conclusion

This document (D6.2) provides reviews and methodological descriptions of how to upscale costs and benefits of climate change adaptation from individual case study level to more generalized EU level. Upscaling has been defined as an activity in which information on a lower spatial scale is translated into information at a higher spatial scale. Literature on studies upscaling climate change adaptation costs and benefits, using a systematic case study approach, appear to be scarce. From the literature review it shows that most attempts for estimating costs and benefits at European or member state level is done by applying large scale models calibrated by only a small number of ground data, often taken from literature. This literature is based on occasional case studies or available dataset. It is also noted that data on damages after climate induced disaster are not systematically monitored and catalogued or not freely available. Think off flood damage data from insurance companies, success rates of health programs, indicators for ecosystem services. This is especially worrying since often these damage data may represent larger uncertainties then already caused by climate and hydrological changes.

In general it can be concluded from the literature review, that although the evidence base is growing, that studies lack in comparability, and therefore transferability of results is poor. To mention a few reasons: focus on different types of measures, sectoral versus cross-sectoral cases, unclear delineation of what costs can be attributed to adaptation and what to other needs, the treatment of autonomous adaptation in the damage function and varying transaction costs at different scales

In BASE, we developed methodological frameworks and approaches for such upscaling processes to contribute academic advancements as well as benefit policy decision making at national and EU level. The BASE team has explored two approaches for upscaling processes and combined both approaches during case study implementations stage to produce upscaling results.

The first upscaling approach is to use case study clusters – grouping similar case studies (executed under WP5) and draw common lessons and experience which can be benefit to national and EU level. Methods employed for this approaches include *qualitative accumulation* of case-study evidence and *meta-analysis* (quantitative analysis, using statistics) for comparable case study evidence. All case studies will generate specific adaptation strategies. Most cases will follow up with estimates of cost and benefits either quantitatively by using cost and benefit analysis or qualitatively by using multi-criteria analysis. The quantitative results can be cross-comparable and produce general understanding of cost and benefit of implementing adaptation in the EU for different sectors. The qualitative results can diverge across case studies, but some good generalisation can be achieved by ensuring similar case study strategies are utilised during implementation stage. In addition, the case study results in part can be used to also to compare with conclusions that result from the top down modelling exercises.

A procedure is presented in which the case studies are guided through a case study economic evaluation protocol that should yield comparability among cases for similar climate impacts and adaptation strategies. In addition the protocol is asking a minimal effort of all cases to come up with economic evaluation data. However since the number of sectors is large and geographic variety is large the expectation is that only for a limited set of impacts and strategies a direct quantitative analysis is achievable. One clear example was presented for the group of 7 city case studies showing that within these geographically very different cases, 5 different climate impacts has to be considered, asking for a large variety in adaptation strategies as well.

The second upscaling approach is via modelling. On one hand, BASE develops different adaptation modelling solutions to assess cost and benefit of adaptation for different key sectors by up-scale technical and scientific modelling studies from local to global levels. On the other hand, BASE develop an adaptive input-output model to estimate cost and avoid damage in adapting natural hazards (e.g. flooding) which is directly impact to event region but indirectly cascaded to regional, national and EU supply chains.

All model groups are using case study results both for calibration and validation. About half of all cases cooperate with the model groups exchanging data that may serve as model input, to calibrate or to validate model results. By improving these models bottom up using the case studies, the resulting calculations can be partly seen as up-scaled knowledge. Note that the models are simplified representations of the ‘real’ case. In BASE for example this means for instance: that the crop model is representing only a representative subset of crops exploited across Europe, that the flood risk model calculates damages for representative households, industries and not for particular objects in particular places and that ecosystem services model is not covering all relevant services. For the coast (there are some case but no model for this ‘sector’) and the water availability (there is a model but no case studies in this ‘sector’) there is a clear mismatch between models and cases. BASE also takes an additional avenue to assess cost and benefit of climate change adaptation by estimating the wider economic impact of implementing adaptation BASE develops a so called ‘adaptive input-output model’ to evaluate the cascaded damage induced by any extreme climate event beyond the physically impact region but to the national and international supply chains. This type of analysis will be focusing on EU cities due to the sector interdependencies and circular flows between economic systems in urban areas. BASE has chosen Copenhagen, Rotterdam and Leeds as case study cities.

In BASE, we have grouped case studies into five clusters (water and flooding, agriculture, ecosystem services, health and urban context) to reflect EU key sectors for climate change adaptation. BASE will, as presented above, use different methods in producing upscaling results for each case study cluster to reflect different characteristics among different case study clusters. Chapter 2 has provided detailed review about available methods in the literature specifically for each case study cluster. Chapter 3 presents the method framework to assess upscaling cost and benefits of adaptation in every case study cluster. Such assessment is further divided into three sub-questions, including the major sectoral costs in adaptation, optimal mix between mitigation and adaptation and economic advantages of implementing adaptation. We recognise that great differences may exist with the same case study cluster across different study sites, we will draw conclusions based on multiple case studies by answering the same set of key questions using similar approaches and assumptions. By doing this BASE will be in a more systematic way in dealing with cases, contribute to a further growth of the evidence base on costs and benefits of adaptation.

The document of D6.2 has addressed the first two sub-tasks listed in Task 6.2. The other two sub-tasks will be fully conducted by M30. The relevant material will be reported in D6.3 and D6.4.

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Appendix A: The tables of deliverable 6.1

Table A1 Impacts per case cluster

	Impact from		
Case cluster	*Sea level rise*	*Precipitation/Evaporation*	*Temperature*
Human settlements and infrastructure	coastal flooding coastal erosion	flooding from extreme rainfall riverine flooding soil erosion other extreme events (storm, snow)	extreme temperatures
Coastal zones	coastal flooding coastal erosion		
Biodiversity and ecosystems	Salinization	water scarcity / droughts	Temperature shifts
Human health	Flooding	Flooding	Extreme temperatures Vector and food borne diseases
Water management	Flooding	Flooding, water scarcity / droughts	
Agriculture and Forestry		Droughts	Temperature shifts

Table A2 Generic and specific measures for building pathways

Characteristic	Generic measure	Example measure
Non-structural ***(applicable to all impacts and sectors)***	Awareness raising	Campaigns, stakeholder meetings, education
	Disaster response management	Evacuation plans, early warning systems, water rationing schemes,
	Economic incentives	Subsidies, taxes, shares, water pricing, nature farming, building codes
	Risk transfer tools	Insurance, catastrophe bonds
	Monitoring and management	Information and communication systems, screening, forest management, permits for (ground)water use,
	Land use planning	Risk zoning, nature conservation areas, connecting nature areas, crop rotation
Structural ***Floods, Human Settlements and infrastructure, coastal protection***	Improving flood defences (engineering)	Dikes, dams, barriers, flood walls, artificial reefs
	Improving flood defences (building with nature)	Coastal sand nourishment, wetlands,
	Giving Space to rivers	Widening, deepening, side channels, green rivers, removing obstacles
	Improving drainage	Increasing capacity, decoupling, permeable pavement, WADI's
	Improving water retention	Upstream basins, emergency retention areas
	Flood proof building and design	Wet- and dry proof building, save shelters, floating houses
Structural ***Water resources management / agriculture /droughts***	Water conservation	Basins, aquifer storage and recovery
	Water saving measures	Drop irrigation, House hold water saving measures
	Ground water management	Water level control,
	Water technology	Recycling of water, desaliniation
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.
	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.

	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.

Table A3 Example tipping points per sector and CC impact

Sector	CC Impact	Generic tipping point
Health	Increase vector borne diseases	Vector habitat establishment (transmission window for relative humidity and temperature conducive to malaria).
	Increase heat stress	Increased intensity and frequency of heat island effects beyond acceptable limits.
Water resources management	Increase in droughts	Water demands cannot be met by supply (risk bases approach)
Water resources management	Increase in droughts Increase in salinization	Water prices too high
		Too frequent closure of freshwater intakes
		Too high use of groundwater
	Increase in low flows	Economic risk for shipping too high
Flood risk management	Increase in peak river flows	Protection standards can no longer be met financially, as flood risk and required investments in protection are becoming too high (e.g. relative to GDP)
Flood risk management **Coastal zones**	Increase in peak river flows Sea level rise	Retention capacity is insufficient
		Economic risk and risk on casualties too high
		Coastal erosion is progressing too fast
Coastal zones **Human settlements and infrastructure**	Sea level rise Peak rainfall events	Costs for drainage become too high
		Public acceptance of current management fails
		Too frequent failure of infrastructure

Agriculture and forestry	Change of seasons	Dying trees
	Droughts	Crops cannot be grown anymore
Biodiversity and ecosytems	Droughts	Key species disappear

Table A4 Intermediate overview of Cost Benefit information that is likely to be delivered

Case-studies	CBA during BASE?	Adaptation Measures	Costs covered	Benefits covered	PRIMATE	Qualitative accumulation	Meta-analysis	Modelling
Jena (UFZ)	YES - CBA and MCA	Renaturation of private garden areas; Renaturation of industrial area; increase in polder area; extensification of farmland; Elevation of cross road; Building a Dam; building of two flood bypasses			YES	YES	YES	Floods
Timmendorf (EI)	YES – Partial retrospective	Coastal defense system in Timmendrof Strand - Dike	Investments and maintenance costs (The costs for implementing this participatory process will be included in the estimation. Furthermore, regular maintenance costs per year will be integrated into the cost analyses. Here, costs for maintenance of the dike for flood protection, but also maintenance of the recreation related area like cycling paths, promenade, etc.)	Avoided damages (The data includes damages to buildings, infrastructure, vehicles, gross value and further parameters); For the quantification of impacts on local tourism services, the analyses will include the estimation of changes in overnight stays and if possible one-day visitors. As far as data can be collected, the income and turnover of new restaurants directly on the dike and the changes of income/turnover of other restaurants/hotels nearby the dike will be analysed	Possible	YES	YES	NO
Copenhagen (DBT)	NO - Exisiting CBA	DAM; Large-movable locks	The calculation of damages is in addition to the direct damage costs also included indirect costs related to lost arbejds-tid/produktion and the like.	Avoided damages; Loss of revenue	Possible	YES	YES	NO
Kalundborg (DBT)	NO – Existing CBA (2010/1)				Possible	YES	YES	NO
Copenhagen (AU)	YES - 'Most probably a partial CBA and analysis of CBAs conducted by CPh'				NO	YES	YES	NO
CASCAIS (FFCUL)	YES	Green Corridors; Reduction in Water leakages in Distribution; Training and Awareness raising;	Full costs	Full benefits	YES	YES	YES	Health
Alentejo (FFCUL)	YES	Water retention Landscape; Alternative far ing practices;	Full costs	Full benefits	YES	YES	YES	Agriculture InVEST
Vagueira	NO -MCA; Scenario Workshop; Exisiting partial CBA	Groin; Longitudinal revetment; Artificial nourishment;	We develop and apply a spatially-explicit approach that allows for the cost-benefit assessment of coastal protection investment options at the local scale, using the shoreline evolution model LTC	Benefit transfer approaches for the valuation of coastal ecosystems	?	YES	YES	No

Table A5 continuation of table A4 for the remaining case studies

Case-studies	CBA during BASE?	Adaptation Measures	Costs covered	Benefits covered	PRIMATE	Qualitative accumulation	Meta-analysis	Modelling
Rotterdam (Deltares)	NO - CEA	Room for river, spatial planning, dikes, barriers and dams	Full costs	Avoided damages	?	YES	YES	Floods IO-model
Prague (Czech Globe)	YES	Flood risk integrated management solutions			YES	YES	YES	Floods
Iberian peninsula	YES				NO	YES	YES	Floods, Agriculture, Heath
Venice (CMCC)	YES - Retrospective				?	YES	YES	NO
Green Roof (Czech Globe)	YES	Green roofs			YES	YES	YES	NO
South Moravian Region (Czech Globe)	YES	Drought adaptation measures for the wine sector			YES	YES	YES	Agriculture InVEST
Usti Region (Czech Globe)	YES	Drought adaptation measures for the farming sector			YES	YES	YES	Agriculture InVEST
South Devon Coast (EXETER)	'MAYBE'					YES	YES	NO
Ecosystem Services (EXETER)	'MAYBE'					YES	YES	NO
Kalajoki River Basin (Syke)	YES - MCDA; CBA	flood risk management measures						Floods
LEEDS	YES	Urban Flood Risk			YES	YES	YES	IO Model