Cover Delivery Report

Title	Report on review of available methods for cost assessment
WP Number	WP 3
WP Leader	WU
Delivery number	D 3.1
Relative task(s)	Task 3.1
Involved beneficiaries	WU, SEI, IIASA
Author(s)	Xueqin Zhu and Ekko van Ierland
Related to deliverable number(s)	D 3.2
Date of completion	1 July 2010
Submission Date	13 September 2010
Date of approval by the WP Leader[1]	

To complete by the Coordinator

Approved by the Coordinator[1]	
Listed[1]	

[1] The WP Leader sends personally the deliverable and the Cover Delivery Report to the Project Manager by email

Acknowledgement

We appreciate the useful comments from Paul Watkiss and Rob Swart on the first draft.

Table of contents

Preface

This report is written in the context of the EU funded research programme MEDIATION. A common platform for sharing a diverse set of methods and tools for assessing climate change impacts, vulnerability and adaptation is required to help reduce Europe's vulnerability to climate change. The primary objective of the MEDIATION project is to develop such a platform and an integrated methodology to support adaptation policy development at different levels in Europe, using the results of national, EU and international research programmes. The main objectives of the project are the following:

A. Defining the policy needs: to assess the knowledge requirements associated with the ongoing impact assessment and adaptation policy developments in Europe in various decision domains, in consultation with the appropriate decision-makers and stakeholders;

B. Reviewing, linking and improving or developing appropriate methods, tools and metrics: to identify, consolidate, complement, apply and test available methods and tools for analysing and assessing impacts, vulnerability and adaptation options, including but not limited to cost-effectiveness criteria, focusing on a selected number of case studies;

C. Developing an overarching integrated methodology: to integrate available knowledge from previous national and international programmes and projects into an integrated methodology (or framework) to analyse and assess impacts, vulnerability and adaptation options;

D. Making a tool box available and disseminating the project results: to make the methods and the knowledge available through a designated common platform, designed to last beyond the project's lifetime, flexibly incorporating new knowledge, and disseminating the project results in Europe.

From earlier European and national research a fragmented landscape of methods and tools is available. MEDIATION reviews these methods and tools, link them to policy needs, improve them if needed and feasible, and make them accessible to users through a common platform. Special attention is paid to metrics. Metrics are here understood to be indicators that could be used for international comparison of impacts, vulnerability and the cost-effectiveness of adaptation options. Both climate change impacts and the costs and benefits of adaptation options are very uncertain, and therefore a major element in the project will be the management and communication of uncertainties, and where possible, the reduction of “known” uncertainties in order to facilitate robust decision-making. Furthermore, given their central relevance, the project not only addresses potential gradual, average changes in climate, but also evaluates the implications of changing characteristics of extreme weather events, and of low-probability, high impact events. The central deliverables of the project are: (a) a common platform that makes assessment methods and metrics accessible, and (b) an integrated methodology linking decision domains with appropriate methods.

Focusing on the integrated methodology and common platform, MEDIATION is organized in five work packages, of which work package 3 (WP3) is on the methods and metrics for socio-economic evaluation of adaptation strategies including cost-effectiveness. It aims to building a consolidated set of methods and tools for assessment of socio-economic aspects of impacts, vulnerability and adaptation options at relevant levels. Particularly, WP3 is reported in five deliverables:

1) Review of available methods for cost assessment (D3.1);

2) Review of available methods for cost-effective assessment (D3.2);

3) Review of available methods for socio-economic assessment (D3.3);

4) Framework for costs, cost effectiveness, and other methods for socio-economics assessment (D3.4);

and

5) Results of applications to case studies (D3.5).

The current report serves as the first deliverable (D3.1), which reviews the existing methods for assessing the costs of adaptation options and the wider context in which they can be used.

1. Introduction

Adaptation is defined by IPCC as an "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities". There are multiple types of adaptation, including anticipatory, reactive, autonomous and planned adaptation (UNFCCC, 2010). For the MEDIATION project, we focus on the planned adaptation. Planned adaptation refers to adaptation that requires some level of organizational or policy intervention. It includes not only the hard technical options such as dikes, but also soft non-technical measures such as socio-institutional issues which may influence behaviour. Within MEDIATION, we are primarily interested in the European to national-level policy domain as this is likely the main users of the platform. To identify and evaluate alternative adaptation options, a variety of assessment methods has been developed and conducted in various cases at different levels.

Adaptation costs are the costs for planning, preparing for, facilitating, and implementing adaptation measures, including transition costs, while adaptation benefits are the avoided damage costs or the accrued benefits following the adoption and implementation of adaptation measures (IPCC AR4, 2007). It would be useful to supply information on both costs and benefits within an adaptation decision framework, allowing decision makers to make informed decisions between options, allowing trade-offs and providing a means to justify decisions. However, many studies so far have focused on the costs of adaptation and have not assessed the benefits of adaptations. This is partly caused by difficulties in collecting the data and in estimating the economic benefits.

Although more specific information is available on the magnitude of the future climate change impacts across a wide range of systems and sectors and across the regions of the world, methods for adaptation costing are not fully understood (IPCC, 2007). Only limited adaptation assessments were developed and conducted with the aim to evaluate adaptation options. For example, Canada (Lemmen et al, 2008), Finland (MMM, 2005), the Netherlands (De Bruin et al., 2009) and the UK (DEFRA, 2006) have conducted national adaptation assessments or developed national strategies to adapt to climate change. However, compared to other aspects, there remains a very low evidence base on the economic aspects of adaptation. The IPCC AR4 reported the literature on adaptation costs and benefits as 'quite limited and fragmented' (Adger et al., 2007), and the OECD study on the 'Empirical estimates of adaptation costs and benefits' (Agrawala and Fankhauser, 2008) found little quantified information even on the costs of adaptation, except in a few sectors (e.g. coasts). Recently, a UNFCCC study (UNFCCC, 2010) on the ‘Potential costs and benefits of adaptation options’ found the continued lack of detailed analyses of the costs and benefits of adaptation, including in a form that is relevant to decisions on public funding. There is a need for further methodology development, including the treatment of uncertainty, economic valuation and equity. Clearly, this is one of the major 'gaps' requiring urgent attention in progressing analysis.

Assessments of climate change impacts, adaptation and vulnerability are undertaken to inform decision-making in an environment of uncertainty. The IPCC (2007) identifies five approaches: impact assessment, adaptation assessment, vulnerability assessment, integrated assessment and risk management, each of which accommodates a variety of different methods. For adaptation assessments, the UNFCCC (2010) summarised a broad range of methods identified by IPCC (2007), which includes:

• Scenario-based approaches, where climate risks are scoped qualitatively or quantitatively and adaptation options are identified.

• Technological assessments, which extend to include future adaptation options (that differ from those currently available) under alternative socio-economic scenarios.

• Normative policy assessments, which use the outputs of vulnerability and/or risk assessments to assess acceptable adaptation options or strategies.

• Risk management methods, which combine current risks to climate variability and extremes with projected future changes, using alternative decision support tools to assess adaptation.

• Anthropological and sociological methods, which identify learning in individuals and organisations and the processes needed to effectively adapt to climate change risks.

• Adaptive Capacity Assessments, which considers investment in adaptive capacity in a way similar to adaptation options.

• Cost-Benefit Analysis (CBA), where the benefits and costs of adaptation are expressed in monetary terms, and the net benefits or costs calculated.

• Non-formalised cost-benefit analysis, where costs and benefits are compared, using monetary and non-monetary terms as part of multi-attribute analysis.

• Cost-effectiveness Analysis (CEA), which is often used to assess alternative adaptation options or the least-cost path to reaching a given target (e.g. a predefined threshold level).

• Multi-criteria analysis (MCA), which allows consideration of quantitative and qualitative data together using multiple indicators.

• Portfolio Theory, which borrows principles from financial investment to maximise the expected rate of return for a portfolio as a whole rather than individually.

• Participatory techniques, which base analysis on direct participatory approaches.

The most typical methods for appraising adaptation options (decision support) used in the literature include Cost Effectiveness Analysis (CEA), Cost-Benefit Analysis (CBA), and Multi-criteria Analysis (MCA) though other approaches have been adopted. In relation to the climate change impacts and the overall economy impacts of adaptations, applied general equilibrium models have occasionally been used. High level adaptation costs have also been assessed in some of the so-called integrated impact assessment models. Other methods such as optimization models, scenario analysis and real options analysis are also used in different cases of climate change analysis. As the focus of the MEDIATION project, in this report we will discuss these methods and their advantages and disadvantages for applications.

The organization of the report is as follows. In Section 2 we will provide a general framework for costing assessment in a decision making context. Section 3 is about cost-effectiveness analysis and some applications in adaptation analysis. Section 4 is on cost-benefit analysis and related issues (e.g. indirect effects and discounting). The indirect benefits require a general equilibrium (GE) framework, where the objective is to maximize the social welfare considering the possible adaptation measures. Section 5 is about multi-criteria analysis and some applications in adaptation analysis. Section 6 focuses on some optimization models considering the interaction between climate change impact and economy (production). The examples of this type of models include the integrated assessment models (IAMs), cropping system models (Cropsyst models) and dike-height control models. In section 7, methods (i.e. scenario analysis and real option analysis) for incorporating specific issues such as risk and uncertainty are discussed. Finally, in section 8 we will conclude with some recommendations regarding assessing costs and benefits of climate adaptation measures.

2. The general framework of cost assessment in decision-making context

Before detailed costing methods are discussed, it is worthwhile to discuss a detailed framework which can be applied in the context of climate change analysis. It is an important challenge to define a coherent adaptation strategy and to develop adaptation measures that are well designed and flexible, and that meet various criteria such as efficiency (in spatial and temporal perspective), coherency (e.g. in integrating cross sectoral aspects), innovativeness (in terms of exploiting new technological options and new options provided by climate change) and effectiveness. Particularly if developing countries are involved in the analysis, equity will be another important criteria, but it is also relevant in industrialised countries.

Methodologies for costing adaptation measures pose some specific problems such as dealing with long-term risk, discounting, economy-wide effects and uncertainty issues. There are also other related issues including:

- Challenges with the development and definition of the future baseline (including socio-economic development).
- The attribution of costs and benefits of adaptation, i.e. the separation and attribution of future climate change.
- The level of spatial and disaggregation.
- The linkages with mitigation, and any synergies or conflicts.
- The consideration of ancillary impacts or benefits from action.
- The challenges in assessing benefits, and even costs, for many non-technical (soft) or non-market adaptation options.

A scenario based ‘impact assessment’ approach with costing adaptation involves: identifying and measuring (quantifying) climate impacts in physical units; converting these physical impacts into monetary values; calculating the resource costs of adaptation options, and weighing up the costs and benefits of adaptation options and choosing the preferred option, taking account of risks and uncertainties (Metroeconomica, 2004).

This approach is used widely. For example, it can be observed in a similar research program (Knowledge for Climate Change) in the Netherlands. Its objective is to improve the tools for defining the adaptation challenges for the various sectors and areas in Europe and to develop, to improve and apply tools for the development of a coherent strategy for adaptation and implementation of practical adaptation measures, and to improve the evaluation tools to further optimize the options and to select the best packages of adaptations options. This can be addressed the following research questions:

1. How can - in a dynamic context and given the uncertainties related to climate change- the targets be identified for adaptation in the various sectors and the various regions of the EU and what will be the desired timing?
2. How can a consistent adaptation strategy and alternative and innovative adaptation options be generated, both in terms of changes in infrastructure and changes in behaviour and society, in order enhancing climate resilience of the EU?
3. How can assessment and evaluation tools be developed and applied for adaptation in the various regions in the EU and for the various sectors and hotspots, including crosscutting issues?

For research question 1 this requires new socio-economic methods to consider uncertainty issues and climate change impacts and issues like the optimal timing of the various targets for adaptation (How much needs to be done and when?)

For research question 2 we need to identify in close collaboration with the stakeholders in the various cases of MEDIATION what alternative options are available, ranging from technical to behavioral and institutional options and what are the most promising ones and how can this be integrated in a consistent adaptation strategy?

Under research question 3 we will focus on the urgent and remaining issues related to the costs and benefits of the options, in particular the optimal timing of the implementation, the cross sectoral issues, discounting and the flexibility in the timing of the various steps in the implementation of the strategy and the relevant adaptation options.

Figure 1 shows the adaptation research approach based on the impact assessment approach. In the top segment of *Assessment of climate change impacts* we focus on the assessment of climate change impacts by means of socioeconomic scenarios. Here scenario analysis can play an important role. In the domain of *Design of adaptation options* we focus on interactive development of spatial adaptation strategies and communication of adaptation in consultation with stakeholders. In the third domain of *Evaluation of adaptation options* we focus on the costs and benefits of the options and the selection of the best options using different methods based on the various criteria, such as efficiency, equity, spatial impacts, and timing. For this purpose, costing methods such as cost-benefits analysis, cost effective analysis, multi criteria analysis, and integrated assessment models can play a role, which we will give a critical review first in this report.

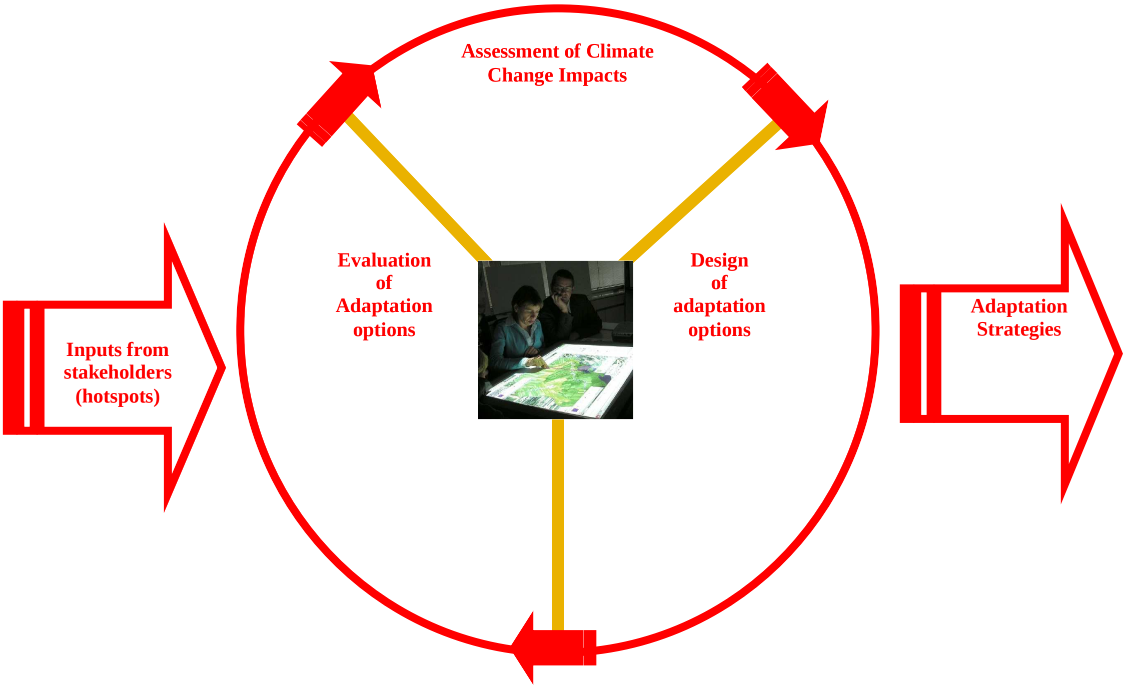

Figure 1 Outline of the research approach (based on van Ierland et al. , 2010)

Alternative approaches do, however, exist and have been applied, for example in the context of vulnerability assessments or adaptation assessments.

The general methodological frameworks also adopt different assessment tools (decision support tools) for prioritising adaptation, which use information on the costs and benefits of adaptation. The tools include the CEA, CBA and MCA among others.

3. Cost effectiveness analysis (CEA)

Cost effectiveness analysis (CEA), as defined by the IPCC, "takes a predetermined objective (often an outcome negotiated by key stakeholder groups in a society) and seeks ways to accomplish it as inexpensively as possible" (Ahmad et al. 2001). The aim of CEA is to find the least costly option or options for meeting selected physical targets.

The easiest way to think about CEA is to assume that there is a single indicator of effectiveness, E, and this is to be compared to a cost of C. The usual procedure is to produce a cost-effectiveness ratio (CER): $CER = \frac{E}{C}$. If we suppose that there are i=1, 2, …, n potential policies, with corresponding costs C_i and effectiveness E_i then CEA requires that we rank the policies according to $CER_i = \frac{E_i}{C_i}$.

A classic application of CEA is to derive cost curves, in order to explore the least cost way of achieving pre-defined ambitions or targets. This can be undertaken for adaptation, at a sectoral or sub-sectoral or to assess individual types of risk. However, cost effectiveness cannot be used to compare adaptation between sectors, as has been applied for mitigation, because there are no common metrics. An emerging issue is the recognition that climateproofing of all human activities through adaptation would be extremely expensive, and there will be many cases where benefits will certainly exceed costs. At the other extreme is a policy of doing nothing, i.e. living with the risks of climate change. Optimal policy will be somewhere between these two extremes (i.e. 'cost-effective and proportionate'). The concept of cost-effective and proportionate adaptation is a sound one, but assessing this in practice will clearly be complex. Whilst there has been much attention focused on the effectiveness of adaptation in reducing climate change vulnerability, and so potential impacts, it is rarely appreciated that if done badly, adaptation responses can actually exacerbate the effects of climate change. In analyzing the costs and benefits of adaptation it is also necessary to consider such "mal-adaptation" as a non-cost-effective adaptation measure. A strong theme will be to identify low cost and no regret measures.

There are a number of potential barriers to ranking adaptation options according to cost-effectiveness: (a) adaptation responds to a local impact and the benefit achieved by adaptation is primarily local/regional, and is determined strongly by local conditions, and (b) adaptation is sector specific, addressing different types of climate signals and impacts.

There are therefore no universal or consistent metrics in relation to what a given level of adaptation achieves – it varies according to whether the option is responding to impacts from average temperature changes or sea-level rise, or the change in probability (or magnitude/frequency) of extreme events such as flooding. Thus it is not easy to compare the cost-effectiveness of adaptation options across different sectors, or between different types of measures (for instance, there is not a common metric of benefit between a reduction in risk from coastal flooding vs. cooling demand delivered from a passive air cooling system in response to higher summer temperatures). There may be complex issues of additionality – separating out the climate change component of current weather variability from improved climate resilience to climate change. There may also be differences in the adaptation response achieved (in magnitude) according to whether implementation is proactive or reactive, or according to the specific time period when the measure is implemented, both in terms of costs, but also in relation to the adaptation benefits achieved. Furthermore, the effectiveness of adaptation measures may vary across actors depending on their ability to adapt (adaptive capacity) and their exposure to risk (vulnerability). Finally, the cost-effectiveness of options may vary according to the discount rate used, and this may be important particularly for longer-term options.

A further issue with CEA is the process of selecting the effectiveness measures. The measure of effectiveness could be based on some attitude survey of a random sample of individuals. In practice, CEA tends to proceed with indicators of effectiveness chosen by experts. Rationales for using expert choices are: a) that experts are better informed than individuals, especially on issues such as habitat conservation, landscape etc., and b) that securing indicators from experts is quicker and cheaper than eliciting individuals' attitudes (Pearce et al., 2006).

CEA has been applied to sectoral assessment of many national studies e.g. health, freshwater systems, coastal and river flood risks, extreme weather events and biodiversity and ecosystem services. Examples in the health sector include the calculation the climate related health effects in terms of life years lost or disability-adjusted life years lost (Markandya and Chiabai, 2009; McMichael et al, 2004).

CEA is suitable for assessment between options, using units other than money, thus it has potential for effects that are difficult to value. CEA can only offer guidance on which of several alternative policies (or projects) to select, given that one has to select one, i.e. it is a relative measure. CEA can be done in conjunction with standards of acceptable risk or acceptable cost per unit of impact removed. For example, when it is difficult to value the consequences of extreme events such as flooding, CEA can be used for defined or acceptable levels of risks. Alternatively, we can set expected losses from such events at an agreed level (such as the current level of losses) and to undertake adaptation measures at the lowest cost, so as to not exceed that level.

The limitation of CEA is that an entire list of policies, ranked by their cost-effectiveness, could be adopted without any assurance that any one of them is actually worth doing, i.e. that they are justified in absolute terms. The notion of "worth doing" only has meaning if one can compare costs and benefits in a manner that enables one to say costs are smaller than benefits.

4. Cost Benefit Analysis (CBA) and general equilibrium (GE) models

Adaptation has a cost, e.g. defined by the IPCC as the "cost of planning, preparing for, facilitating and implementing adaptation measures, including transition costs", but also a benefit, expressed as "the avoided damage cost or the accrued benefits following the adoption and the implementation of adaptation measures". In the simplest terms, if the economic benefits of adaptation such as the reduction in climate change impacts (or the potential positive consequences) outweigh the costs, then there are net benefits – if not, then this potentially leads to mal-adaptation. This overarching principle is important because resources need to be allocated efficiently between different adaptation strategies and between adaptation and mitigation strategies. This can be done only if costs and benefits of the different options are clearly determined (though note that benefits do not have to be in monetary terms). Cost benefit analysis is one of the tools to determine the costs and benefits, which leads to the decision of accepting or rejecting an option.

The essential theoretical foundations of CBA are: benefits are defined as increases in human well-being (utility) and costs are defined as reductions in human wellbeing. For a project or policy to be justified on cost-benefit grounds, its social benefits must exceed its social costs. Hence CBA is also called societal CBA, if cost and benefits are assessed from the perspective of society as a whole. The initial step of CBA is to determine whose costs and benefits and the time horizon over which costs and benefits are counted. Second, CBA has to consider the time-preference through the process of discounting because individuals have preferences for when they receive benefits or suffer costs. Costs and benefits are rarely known with certainty so that risk (with probabilistic outcomes) and uncertainty (when no probabilities are known) also have to be taken into account. The decision rule for comparing costs and benefits is the net benefits criterion. A standard CBA involves calculating the present values of the social costs and benefits of a project or an adaptation option (PVC and PVB) and their difference (NPV) or their ratio (B/C), i.e.

$$PVC = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t},$$

$$PVB = \sum_{t=1}^{T} \frac{B_t}{(1+r)^t},$$

$$NPV = \sum_{t=1}^{T} \frac{B_t}{(1+r)^t} - \sum_{t=1}^{T} \frac{C_t}{(1+r)^t},$$

$$B/C = \frac{PVB}{PVC},$$

where C_t is the social costs and B_t is the social benefits of the project in the year t, T is the life time of the project and r is the discount rate.

If $NPV \leq 0$ or $B/C \leq 1$, then the project adds no net welfare to society and the project should not be pursued because society would not be made better-off, if all benefits of adaptations can be quantified and monetised. If NPV>0 or $B/C > 1$, then the project adds welfare to society. All projects with a positive NPV should, in principle, be undertaken because they add to the welfare of society, but budget constraints prevent this from happening. A project with a positive NPV may not proceed because an alternative project has a higher NPV. When there are a number of projects and programs available to decision makers with a limited budget, it is necessary to rank projects.

However, for adaptation, the use of standard CBA can be limited, primarily because of the partial availability of data on the costs and benefits of adaptation options. There are also other reasons, amongst which may be the distribution of impacts, especially on the particularly vulnerable, although these can be accounted for through the inclusion of distributional weights in analysis. Further, CBA fails to account for those costs and benefits that cannot be reflected in monetary terms, particularly such as ecological impacts, as well as concerns that influence welfare, such as peace and security. Subject to this qualification, it can be applied to decisions in some sectors for certain types of adaptation options (e.g. technical measures for flood prevention), or in sectors where there is a major private sector involvement (UNFCCC, 2010).

Richards and Nicholls (2009) applied cost-benefit analysis to some adaptation options (raising dykes and beach nourishment) in the costing and adaptation module of the DIVA model for assessing impact and vulnerability of the coastal systems in Europe and determining the level of adaptation. The specific adaptation assessment options focused on reducing flood risk through the construction and increase in height of flood defence dikes and reducing beach erosion through placing of additional sand onto exiting beach areas, which are considered public-funded and the coast is seen as a public good, and hence all adaptation costs are considered to be public investments. The costs include the sand costs for beach nourishment, the construction costs for national dike, and other costs related to increased river flooding in the lower reaches of rivers subject to the influence of sea level and the construction of river dikes. In the DIVA model, it is assumed that the adaptations take place where is economically optimum, as determined by cost-benefit analysis.

Other examples of CBA includes applications to sea level rise as reported in Agrawala and Fankhauser (2008), to fresh water systems (Callaway et al, 2007) and to the agricultural sector (e.g. Rosenzweig and Tubiello, 2007).

Extension of CBA- indirect benefits

The formula for making cost-benefit calculations is straightforward. Problems occur in measuring the actual costs and benefits and in the choice of discount rate (van Kooten and Bulte, 2000). Besides, a standard CBA is based on a strong theoretical foundation with the following important assumptions: only marginal changes in the economy are to be evaluated; no significant distortions in other markets; status of income is given. It is clear that these assumptions impose limits on the interpretation of the results of project evaluation using standard CBA. Particularly, when market imperfections prevail, conventional CBA might underestimate total welfare change, this would lead to biases in decision-making.

A standard CBA cannot deal with the indirect benefits in other markets with imperfection. In these circumstances, a general equilibrium (GE) framework is needed for dealing with indirect benefits and/or costs because GE models can consider market interactions and imperfection and can contain externalities.

For example, indirect benefits of infrastructure improvement in the case of an imperfect labour market have been analysed in a spatial general equilibrium model (Zhu et al., 2009), where direct welfare impacts in transport market and indirect welfare impacts through changes in regional unemployment level were calculated. It showed that indirect benefits would affect decisions on those alternatives when the costs and benefits are rather close.

Discounting

Another relevant issue in cost assessment is discounting. The discount rate *r* has profound effects on the results of CBA - the calculation of NPV and the B/C ratio is sensitive to the rate. What is the appropriate rate of discount to use in weighing future costs and benefits?

For many years there have been disagreements among economists on the right conceptual basis for the social discount rate–the rate at which society should be willing to substitute present consumption for future consumption (Lind, 1995). The issue has gained new importance in the context of climate change policies when we deal with long-term impacts (see, e.g. Arrow et al., 1996). According to Ramsey (1928), the social discount rate is made up of two components: the utility discount rate (also called the pure rate of time preference) and a term that accounts for a declining marginal utility as consumption grows. In this framework, only consumption goods are considered and the social discount rate is also called the consumption discount rate. There is a wide range of rates in use in major studies of climate change (mitigation), with discount rates ranging from 1.4% to 6 % (Stern, 2007; Cline, 1992, Nordhaus, 1994).

Nevertheless, humans also consider the environment in their utility due to its amenity value (e.g. recreation, water quality or historical sites), for which there is no market (van Kooten and Bulte, 2000). Further, there is now a much wider concept of biodiversity and ecosystems providing utility through ecosystems services (Millennium Ecosystem Assessment, 2005). Millennium Ecosystem Assessment (2005) included provisioning, supporting, regulating and cultural services (provisioning services include ability of ecosystems to provide food, supporting services include soil formation, photosynthesis, and nutrient cycling, regulating services affect climate regulation, flood protection, disease regulation, and water quality regulation, cultural services provide recreational, aesthetic, educational and spiritual benefits. The focus of environmental economics recently has been on the valuation of these services, rather than amenity alone. As far as adaptation to climate change is concerned, these ecosystem services should also be evaluated in appraisal of adaptation options.

The timing of an adaptation decision depends on the delay between investment and the delivery of services. One needs to consider future climate and environmental conditions when considering alternative investment profiles under adaptation programme. This has been discussed by Weikard and Zhu (2005). It is suggested that climate change projects and policies can be evaluated using the concept of dual-rate discounting – a consumption discount rate used to evaluate changes in the marketed goods and an environmental discount rate used to evaluate changes in environmental quality. Environmental goods should be discounted at a lower rate than conventional consumption goods, though dual rate discounting is only justified either as a pragmatic device for valuation when future prices for environmental goods are unavailable or when consumption goods and environmental goods are not substitutable.

5. Multi criteria analysis (MCA) and distinction with CBA and CEA

A common tool in appraisal when there are multiple objectives is Multi-Criteria Analysis (MCA). MCA uses the judgements of decision makers or experts on the importance of the various criteria, which are then used to assess options. In MCA, weights are given to each criterion, ideally reflecting the preferences of the decision makers. The weighted sum of the different criteria is taken in order to get an overall score for option, which can be used to rank options.

MCA can prioritise alternative policy options. Based on a thorough analysis of the most suitable criteria that decision makers can adopt in their decision making, a multi-level MCA can categorize and rank promising and feasible adaptation options. The steps include a clear problem definition, which includes the identification of all alternatives, selection of a set of criteria and assessment of scores. Then the scores are standardized and the weight of each criteria is determined.

Multi criteria analysis is a potentially elegant method to assess alternative policy options, on the basis of a set of alternatives and an explicit set of criteria. The main problem is that such an approach is inevitably subjective, and/or requires very large stakeholder input, in relation to the scoring and weighting assessments. When choosing the weights, a natural candidate is equal weights; this mirrors an unweighted summation of the scores. Another relevant weighting is to give a higher weight to urgency, thereby indicating that this is the most important criterion. There is a scope for the use of MCA in those areas where monetary benefits are only a part of the criteria used.

This approach has for instance been used in de Bruin et al (2009) in the context of the Dutch Routeplanner project. In this project, a multi-level MCA was carried out to categorize and rank promising and feasible adaptation options in the Netherlands. The weights used in the MCA was based on expert judgement because experts are capable to compare options across various sectors with a broad multi-sectoral perspective (De Bruin et al, 2009). Another example of an adaptation decision matrix, in a form of MCA, is the water resource planning case study in South Africa (USAID, 2007).

Distinction between CBA, CEA and MCA

It is important to notice the differences among these three different methods (MCA, CBA and CEA). Particularly, CBA can handle optimisation, it can also provide an absolute measure of desirability, albeit judged by only one criterion: economic efficiency. CBA has comparatively heavy data requirements. MCA is suitable when quantification and valuation in monetary terms is not possible. MCA is normally used for the ranking of options, or prioritisation. Subjective judgement plays an important role in this method, making outcomes more arbitrary than CBA. CEA is a method that falls between CBA and MCA. As is the case with MCA, CEA only produces relative rankings. Given the CBA is the more objective method and can handle optimisation, it may be the most desirable option (OECD, 2009). However, this depends on the analysis. In cases where important criteria cannot be accommodated in CBA (such as sociological and cultural barriers), or when benefits cannot be quantified and valued (e.g. the benefits of preserving biodiversity), MCA may be preferred. If desired, the outcomes of CBA can be incorporated into MCA, making the overall analysis a hybrid one.

Compared to CEA, MCA involves multiple indicators of effectiveness. Technically, CEA can work with multiple indicators but is primarily used for single common goals (e.g. reductions in emissions of greenhouse gas emissions, achievement of levels of acceptable risks). Like CEA, policy or scheme cost in an MCA is always (or should always be) one of the indicators chosen. As with CEA, when effectiveness is compared to cost in ratio form MCA cannot say anything about whether or not it is worth undertaking any project or policy. Its domain is to restricted to choices between alternatives in a portfolio of options or to the choice of doing nothing. Both MCA and CEA are therefore “efficient” in the sense of seeking to secure maximum effectiveness for a given unit of cost, but may be “inefficient” in the sense of economic efficiency (depending on the original goal or target).

Criteria in MCA may or may not be measured in monetary terms. MCA differs from CBA in that not all criteria will be monetised. MCA tends to be more transparent than CBA since objectives and criteria are usually clearly stated, rather than assumed. Because of its adoption of multiple objectives, MCA tends to be less transparent than CEA with a single objective, although also more comprehensive, with the ability to tackle multiple attributes many of which it is not possible to monetise.

An adaptation option would represent a good investment if the aggregate benefits exceed the aggregate costs. Although CBA is important, other criteria are also considered when making a decision because CBA does not cover all aspects: it ignores the distribution of the costs and benefits of adaptation options and it fails to account for those costs and benefits that cannot be reflected in monetary terns, such as ecological impacts, as well as concerns that influence welfare, such as peace and security. Therefore, CBA is only one input into the decision-making process, and other approaches (CEA, MCA and others) are often used as a complement or a substitute.

6. Optimisation models

Optimisation models can be used for determining the optimal level of climate change adaptations. For different circumstances, different optimisation problems may be relevant. For example, integrated assessment models consider explicitly the damages from the climate change in an economic optimization, where adaptation options can be a constraint to the damage functions. Cropping system models consider the climate change impacts on the crop growth therefore the optimal cropping patterns can be determined. Dike-height control models can determined the optimal height and timing of a dike for predefined levels of acceptable flood risk, minimising the total costs of flooding and investment.

IAMs

The aggregated estimates of the costs and benefits of adaptation can be assessed by some of the global economic integrated assessment models (IAMs). These models are primarily focused on estimating the economic costs of climate change, and the costs of mitigation, for which they can provide estimates at the global and continental levels, though with adjustments, they can also provide outputs for regional and national assessment. Some of the models can also consider adaptation, but there is much greater variability here. A small sub-set of the IAM models can analyse optimal investments in adaptation, with the time profile and the trade-off between adaptation and mitigation in an optimizing framework (Bosello et al., 2010). These models are optimal growth Integrated Assessment models endowed with an adaptation module to compute the costs and benefits of policy-driven mitigation and adaptation strategies. The examples include the AD_DICE model (De Bruin et al, 2007), the FEEM-RICE model and the AD_WITCH model (Bosello et al., 2010). However, such assessments are highly controversial. The consideration of adaptation in these models is highly theoretical and furthermore, many consider that it is not possible – or desirable – to consider mitigation and adaptation as direct substitutes as these models assume.

Cropping system models

For agricultural analysis very often optimization models are used that identify optimal cropping patterns for characteristics such as various soil types, soil quality or water availability. Particularly, the Cropsys models are interesting candidates for studying interactions between agricultural production and adaptation to climate change. A CropSyst model is a cropping systems simulation model that is widely used and found applications in all continents (e.g. Stöckle et al., 2003). These models simulate crop production and environmental impact in response to soil, weather, and management. They accommodate responses to climate change and increased atmospheric carbon dioxide concentration, and can be used to evaluate carbon sequestration and greenhouse gas emissions resulting from agricultural activities. These models can be used to assess the changes in the agricultural sector that can be expected as a result of climate change and the best adaptation options. These models need to be calibrated and validated for the site and crop variety of interest. Of course in order to apply these models scenarios for future climate change are required at a very detailed level.

A good application of the CropSyst model is in Tubiello et al. (2000), which investigated the potential effects of future climate change on agricultural production of four different cropping systems at two Italian locations, Modena and Foggia. They found that the combined effects of elevated atmospheric CO_2 and climate change at both sites would depress crop yields if current management practices were not modified and that adaptation to climate change may be limited for irrigated crops, depending on site-specific water availability. These type of models can be applied for different risk attitudes, such as risk aversion, risk neutrality and even for risk loving agents.

Dike-height control models

For water management issues optimization models are used to assess the optimal dike height and the interval by which the dikes needs to be reconstructed and heightened. In the Netherlands detailed analysis is done with the dike-height control model (Eijgenraam, 2006), where the social welfare is maximised by minimising the present value of the total costs of flooding and investment over the whole future. The analysis focuses on the costs and benefits of raising the dikes for two reasons: the value behind the dike increases over time, and this would require raising the dikes; and the external circumstances: sea level rise, and excessive precipitation and run-off in rivers due to climatic change.

7. Approaches to analysis of adaptation under uncertainty

The assessment of climate change impacts, vulnerability and adaptation has to address a wide range of various types of uncertainties. Large uncertainties are associated with higher-resolution projections of regional or even local climate change effects, and these pose great difficulties when it comes to assessing the need for and the costs and benefits of adaptation strategies. The same applies to uncertainties regarding socio-economic vulnerabilities. In some cases these uncertainties are likely to be reduced in the future by improving models; in other cases, however, uncertainties cannot be reduced significantly and decisions need to be made in the face of these uncertainties. It is inherent to advancing climate change research that new, unexpected uncertainties will emerge.

Because the proposed platform is to support policy-relevant assessment of impacts, vulnerability and adaptation, MEDIATION carefully looks at the understanding, management and communication of uncertainties in a policy context rather than solely focusing on reducing uncertainties. There are the IPCC guidelines for handling uncertainties and evaluating their applications (Swart et al., 2008). These methods have been further used and developed by other assessments, but not in a consistent manner. Especially the treatment of uncertainties in adaptation is a very new area, only explored by a very limited number of studies to date (Dessai and van der Sluijs, 2008). In assessing uncertainties, it is essential to be informed by a multi-disciplinary body of theory, much of which shows that people and institutions respond to uncertainties in ways that are nonlinear and often inconsistent with a desire to optimize future expected benefits.

The assessment of current and future adaptations to climate change and variability, adaptive capacity, multiple stresses and adaptation in the context of sustainable development needs different approaches for decision-making under uncertainties. We will discuss four potentially relevant approaches: the scenario-driven approach, the Real Options approach, portfolio analysis and robust decision making.

Scenario–driven approach

Adaptation assessments ideally require information on how conditions such as climate, social and economic development, and other environmental factors are expected to change in the future. This commonly entails the development of scenarios. Scenarios are plausible descriptions of the possible future states.

Current studies on adaptations under uncertainty mainly use the standard climate scenario-driven approach. Much of the climate research in Europe is making use of the IPCC Special Report on Emission Scenarios (SRES) scenarios in their assessment (Nakicenovic and Swart, 2000). The IPCC SRES four scenarios of future greenhouse gas emissions, accompanied by storylines of social, economic and technological development, provided a coherent global quantification of socio-economic development, greenhouse gas emissions and climate, and represented some of the most comprehensive scenarios. However, these scenarios are less relevant to the assessment of adaptations to climate change in the EU context.

Improved scenarios are required for poorly specified indicators such as future technology and adaptive capacity, and interactions between key drivers. An example for the future technology is the learning curve. Figure 2 shows the hypothetical learning curves for solar and wind energy. It shows that as the production quantities increase, the energy production costs go down due to the learning effect and economies of scale. But the two technologies have different slopes. When the production quantities are small ($q<q^*$), wind energy is cheaper than the solar energy. But over time solar may become cheaper because the production costs of solar energy might decrease because it is possible to use very thin photovoltaics plates while wind energy costs are hard to decrease because metal is still needed for the construction of wind mills. This type of learning curve for future technological scenarios is one of the ways to assess the adaptations to climate change under uncertainty. More promising adaptation technologies can be assessed as well.

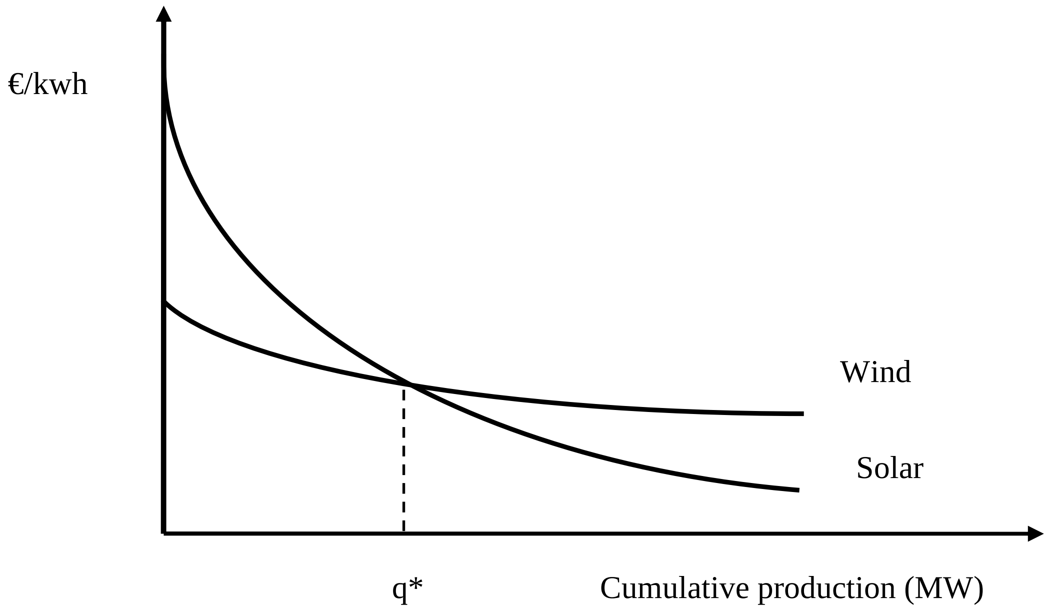

Figure 2 Hypothetical learning curves for Solar and Wind energy

Different systems, sectors and regions have different responses to climate change and different adaptive capacity, therefore scenarios for adaptation should be sector- and location- specific. Uncertainties related to future human choices can partly be addressed through socio-economic scenarios. All these characteristics should therefore be reflected in the different case studies in the MEDIATION project.

Real Options approach

In a supplementary Green Book Guidance of UK (2009), a Real Options analysis is proposed for accounting for the effects of climate change under uncertainty. A “real option” is an alternative or choice that becomes available thorough an investment opportunity or action. A Real Options analysis is suitable for policies, programs or projects which have three core features: uncertainty, flexibility and learning potential. Flexibility is an important factor to be considered in appraising policies, programmes and project, because given uncertainty over future climate, decisions that would be difficult or expensive to revise in future should receive additional scrutiny. Real Options analysis provides a framework to incorporate the uncertainty of climate change and the value of flexibility into decision making. A Real Options approach follows the same principles as a cost-benefit analysis but with an additional step to account for the value of flexibility in the structure of an activity. Particularly in a quantitative Real Options appraisal, streams of costs and benefits should be compared over time and discounted to generate a net present value (NPV). In addition, a decision tree can be made with information on costs and benefits and probabilities associated with different options. Using a decision tree, the NPVs of a proposal *with the option to revise in the future* can be calculated, which is different from the standard NPV calculation. Thereafter, a decision can be made based on the NPV considering different options.

.

Portfolio analysis

Portfolio theory (PT) frame cost-benefit analysis within a more explicit treatment of uncertainty. It allows adaptation decision maker to trade off economic efficiency, measured by the net present value, directly against uncertainty, measured as variance of NPV.

Hunt (2010) explained the basic procedure of portfolio-based decision framework in the specific context of the riverine flood risk posed by climate change. First, we identify alternative adaptaion options. There are three alternative options in this specific case – engineering based defences, property resistance measures and flood warning mechanisms. Second, we estimate the benefits and costs of the alternative options. Third, uncertainty from climate change and socio-economic change is introduced by formulating alternative climate and socio-economic scenarios. Fourth, we need to estimate the potential effects of these scenarios on the benefits and costs for these scenarios. Fifth, we incorporate the outputs of cost-benefit analysis under different scenarios into portfolio analysis of the alternative options. Specifically, we construct a number of portfolios using combinations of 2- or 3- options, implemented to varying degrees. Then we estimate the expected NPV and variance of the individual portfolios. Finally, the results of the portfolio analysis shows a locus of portfolios with different levels of NPV and variance. The higher expected NPV means higher economic efficiency, and a higher variance means a higher level of uncertainty. Sub-optimal portfolios that have lower NPV and higher variance than an alternative can be identified and removed from the portfolio possibilities presented to the decision makers. Decision makers can then decide which option will be chosen depending on his preference for the economic efficiency and uncertainty. Therefore, we can also say that portfolio analysis is actually based on a combination of cost-benefit analysis and scenario analysis.

Robust decision making

For decision-making in the context of adaptation to climate change in the long-term under uncertainty, one way is to use a Robust Decision-Making framework. When we are talking about adaptation and vulnerability it is not just changes in climate that will have an effect but also future socio-economic, political, cultural and technological developments (for example population growth, market prices, communication technologies etc), which in many cases will have a greater effect on vulnerability than climatic factors. Robust decision making needs to consider as many as possible factors and scenarios and identify the most acceptable situations (Lempert, Nakicenovic et al. 2004). In the face of this deep uncertainty, decision-makers systematically examine the performance of their adaptation strategies/policies/activities over a wide range of plausible futures driven by uncertainty about the future state of climate and many other economic, political and cultural factors.

The robust decision making is consistent with traditional optimum expected utility analysis, but the order is the other way around (Groves, Lempert 2007 p.76). While conventional analysis characterise uncertainties before ranking options, the robust decision approach starts from selecting decision options and then estimates utilities of options to identify potential vulnerabilities of potential strategies. In other words, the robust decision making is different from conventional sensitivity analysis. The conventional approach studies the variability of outcomes against many input variables. Instead, the robust decision making is to find strategies, which perform well insensitively to the most significant uncertainties.

There are four key elements for a robust decision approach:

- Assembling a large number of scenarios. Such ensembles contain a set of plausible futures as diverse as possible.
- Seeking robust, rather than optimal, strategies that perform "well enough" by meeting or exceeding selected criteria across a broad range of plausible futures and alternative ways of ranking the desirability of alternative scenarios. Robustness provides a useful criterion for long-term policy analysis because it reflects the approach many decisionmakers actually use under conditions of deep uncertainty.
- Employing adaptive strategies to achieve robustness. Adaptive strategies evolve over time in response to new information. Near-term adaptive strategies seek to

influence the long-term future by shaping the options available to future decision makers. The near-term strategies are explicitly designed with the expectation that they will be revised in the future.

- Designing the analysis for interactive exploration of the multiplicity of plausible futures. Humans cannot track all the relevant details of the long-term. Working interactively with computers can discover and test hypothesis that prove to be true over a vast range of possibilities. Computer-aided exploration of scenario and decision spaces can help humans discover adaptive near-term strategies that are robust over large ensembles of plausible futures.

For element one, the robust decision approach assembles futures as a challenge set against which to test the robustness of alternative strategies. It profits from deriving scenario ensembles that provide the greatest possible futures consistent with available information. Information about the future might be in the form of quantifiable physical or economic laws –e.g. matter is conserved, or the average annual rate of economic growth over the entire twenty-century is unlikely to exceed four percent. For example, the IPCC created 4 SRES to identify key driving forces and characterise the range of uncertainty in future greenhouse gas emissions.

For element two (seeking robust strategies), a strategy is considered robust if it performs reasonably well compared to the alternatives across a wide range of plausible futures, while traditional decision analysis seeks the optimal strategy, that is, the one that performs best for a fixed set of assumptions about the future. Concept of robustness provides a computationally convenient basis for identifying policy arguments that are true over an ensemble of plausible futures. It offers a normative description of good choices under deep uncertainty. A robust approach can be quantitatively used by using the so-called regret measure. Regret is defined as the difference between the performance of a future strategy, given value function, and that of what would have been the best performing strategy in that same future scenario. Computer searches across the ensemble can help identify robust strategies- that is, ones with consistently small regret across many futures. In practice, long-term decisionmaking becomes an exercise in juggling difficult trade-offs and judging which values and scenarios should weigh more heavily, and which should downplayed. The choice rest on a complicated amalgam of moral, political and goal-defined judgments.

For element three (employing adaptive strategies), it compares the performance of alternative adaptive decision strategies, looking for those that are robust across a large ensemble of plausible future. These systematic explorations help decisionmakers assess alternative algorithms and choose those near-term actions that can best shape the choices available to future generations.

Finally, for the machine and human interaction, modern information technology makes possible a new and more powerful form of human-machine collaboration to find robust adaptive strategies over time (Lempert et al., 2003).

8. Conclusions

In this report we have sketched a general framework and approaches for decision support for adaptation options in a wide variety of settings. For a classic impact assessment framework, this starts with identifying the expected climate change and its impact. Next this leads to an inventory of adaptation options which need to be assessed. Once a list of adaptation options has been complied, they can be prioritised using various methods, and subsequently, rejected, postponed or selected for implementation. This framework lends itself most readily to monetisation, however, other frameworks adopt different approaches, and involve different aspects.

This report particularly focuses on the various ways of assessing alternative adaptation options in the context of economics and decision support. The major methods include the CEA, CBA and MCA. Individual options for adapting to the impacts of climate change can potentially be appraised within a standard framework of cost-effectiveness analysis (CEA) or they can be compared using monetary values as a common metric in cost-benefit analysis (CBA). The challenge is in trying to compare and aggregate adaptation responses on a consistent basis. The methods and tools to be applied depend on the specific circumstances and the setting of the problems. The major finding regarding to the choice of CEA, CBA and MCA is:

a. In some settings a CEA might be sufficient to identify the least cost solutions to fulfil the standard under the changed climate conditions and provides a ranking of alternative options. CEA is suitable for options that are difficult to value. Examples of application of CEA include health issues, freshwater systemts, coastal and river flodd risks, extreme weather events and biodiversity and ecosystem services.

b. In other settings climatic change requires to make new calculations about the costs and benefits of alternative adaptation options, and this may lead to a revision of existing standards. In such a setting a full CBA can be used where the costs and benefits are considered and by means of discounting the NPV of the alternative projects are established and the project with the highest NPV is being selected. Examples of application of a societal CBA include the assessment of raising dikes against sea-level rise, freshwater systems, and agricultural sector.

c. MCA can be used in cases where a variety of criteria is used to assess the alternative options. This method can be used to identify a priority ranking for adaptation options as a starting point for more detailed assessments and analyses. MCA is suitable when quantification and valuation in monetary terms is not possible. In cases where benefits cannot be quantified and valued (e.g. the benefits of preserving biodiversity, environmental services), MCA is preferred to CBA.

However, it should be noted that there are potential benefits in adopting multiple methods and approaches in an analysis of the costs and benefits of adaptations. It is almost impossible to see how one single approach could capture all of the complex methodological issues raised, address types of adaptation and/or different objectives. There is a need for methodological development to properly address the costs and benefits of adaptation option. The key challenges are related to uncertainty, economic valuation and equity (UNFCCC, 2010). In the context of MEDIATION projects, different methods (or combination of them) should be used for different cases of adaptation options to climate change because of the different objectives and complexity.

Other approaches to the climate adaptation analysis at different levels include optimisation models which can consider the interactions between climate change and economic system. This can be conducted at different levels. For the aggregated level (economy-wide), computable general equilibrium models can be used. At the sector level, cropping system models have also been considered as a tool to identify the optimal cropping patters.

In the case of uncertainty, scenario analysis offers some information for the future impacts of adaptation with uncertainty in climate change and social and economic development, though scenario analysis should be combined with one of the methods discussed above (e.g. extended CBA, portfolio analysis or robust decision theory). Real Options approach is another way to incorporate uncertainty. By using a decision tree with information on costs and benefits and probabilities associated with different options, best strategies can be identified. Besides, portfolio analysis and robust decision theory are also gaining more attention in the filed of climate change adaptation with deep uncertainty.

The report identifies methods and techniques for adaptation options appraisal and decision analysis in the climate change context. It is not meant to provides direct tools for undertaking assessments in the MEDIATION cases. Instead it aims to make an inventory of associated methods for the costs of adaptation options and measures and explore the possible methods which might be used in the current studies. These tools will be further tested in these cases. Then recommendations can be made on what methods or tools might be appropriate according to the specific context, policy objective and type of adaptation. The follow up study in different cases will further investigate the possible methodological innovations for assessment of adaptations in a more consistent way. Using these methods will be important in delivering policies and projects that are successful in the face of an uncertain future.

References

Adger, W.N., S. Agrawala, M.M.Q. Mirza, C. Conde, K. O'Brien, J. Pulhin, R. Pulwarty, B. Smit and K. Takahashi, 2007: Assessment of adaptation practices, options, constraints and capacity. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 717-743.

Agrawala, S. and Fankhauser, S. (Eds.) (2008) Economic Aspects of Adaptation to Climate Change: Costs, Benefits and Policy Instruments. OECD

Ahmad,Q.K., R.A.Warrick, T.E.Downing, S.Nishioka,K.S. Parikh, C. Parmesan, S.H. Schneider, F. Toth and G. Yohe, 2001. Methods and tools. In: Climate Change 2001: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, J.J.McCarthy, O.F. Canziani, N.A. Leary, D.J. Dokken and K.S.White, Eds., Cambridge University Press, Cambridge, 105-143.

Arrow, K.J., Cline, W.R., Mäler, K.-G., Squitieri, R., Stiglitz, J.E., 1996. Intertemporal equity discounting, and economic efficiency. In: Bruce, J.P., Haites, E.F. (Eds.), Economic and Social Dimensions of Climate Change. Contribution of working Group III to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 129– 144.

Bosello, F., C. Carraro & E. De Cian. 2010. An Analysis of Adaptation as a Response to Climate Change. Copenhagen Consensus Center, Copenhagen Business School, Denmark

Callaway JM, Louw DB, Nkomo JC, Hellmuth ME and Sparks DA. 2007. The Berg River Dynamic Spatial Equilibrium Model: A New Tool for Assessing the Benefits and Costs of Alternatives for Coping With Water Demand Growth, Climate Variability, and Climate Change in the Western Cape. AIACC Working Paper No. 31. Available at

<http://www.aiaccproject.org/working_papers/Working%20Papers/AIACC_WP31_Callaway.pdf>.

Cline WR. 1992. The Economics of Global Warming. Washington, D.C: Institute for International Economics.

Dessai, S. and J. van der Sluijs (2008) Uncertainty and Climate Change Adaptation - a Scoping Study. Copernicus Institute, Utrecht University

De Bruin, K., R. B. Dellink, A. Ruijs, L. Bolwidt, A. van Buuren, J. Graveland, R.S. de Groot, P.J. Kuikman, S. Reinhard, R.P. Roetter, V.C. Tassone, A. Verhagen, E.C. van Ierland. 2009. Adapting to climate change in The Netherlands: an inventory of cliamte adaptation options and ranking of alternatives. *Climatic Change* 95: 23-45.

De Bruin, K.C., R. B. Dellink, R. S. J. Tol. 2009 AD-DICE: an implementation of adaptation in the DICE model. *Climatic Change* 95: 63-81.

DEFRA, 2006. The UK's Fourth National Communication under the United Nations Framework Convention on Climate Change. United Kingdom Department for Environment, Food and Rural Affairs, London, 135pp.

Eijgenraam, C.J.J. 2006. Optimal safety standards for dike-ring areas. CPB Discussion paper No.62.

Hope, C. W. 2006. The marginal impacts of CO2 from PAGE2002: an integrated assessment model incorporating the IPCC's five reasons for concern. The integrated Assessment Journal 6: 19-56.

Hunt, A. 2010. Implementing information on the csots and benefits of adaptation in a portfolio –based decision framework. Climate change adaptation conference.

IPCC, 2007 Climate Change 2007 Impacts, Adaptation and Vulnerability. Working Group II. Contribution to the Fourth Assessment, Cambridge University Press.

Lemmen, D.S., F.J. Warren, J. Lacroix, and E. Bush (editors), 2008. From Impacts to Adaptation: Canada in a Changing Climate 2007. Government of Canada, Ottawa, ON, 448 p.

Lempert, R., Popper, S.W. and Bankes, S.C. 2003. Shaping the Next One Hundred Years: New Methods for Quantitative, Long - Term Policy Analysis. RAND, Santa Monica CA.

Lind, R.C., 1995. Intergenerational equity, discounting, and the role of cost-benefit analysis in evaluating global climate policy. Energy Policy 23 (4/5), 379– 389.

Markandya A. and A. Chiabai. 2009 Valuing climate change impacts on human health: empirical evidence from the literature. International Journal of Environemtnal Research and Public Health 6: 759-786.

McMichael AJ, Campbell-Lendrum D, Kovats RS, Edwards S, Wilkinson P, Edmonds N, Nicholls N,Hales S, Tanser FC, Le Sueur D, Schlesinger M and Andronova N. 2004. Climate Change. In: Ezzati, M.,AD Lopez, A Rodgers and CJL Murray. Global and Regional Burden of Diseases Attributable to Selected Major Risk Factors. World Health Organization, Geneva.

MEDIATION, 2009. project proposal.

Metroeconomica, 2004. *Costing the impacts of climate change in the UK: overview of guidelines*. UKCIP Technical Report. UKCIP, Oxford.

MMM, 2005. Finland’s National Strategy for Adaptation to Climate Change. Ministry of Agriculture and Forestry of Finland, Helsinki, 281 pp.

Nakicenovic N, Swart R (eds). 2000. Special Report on Emissions scenarios. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge, UK and New York.

Nordhaus WD. 1994. Managing the Global Commons: The Economics of Climate Change. Cambridge: MIT Press.

OECD, 2009. Policy guidance on integrating climate change adaptation its development cooperation.

Pearce, D., Atkinson G., and S. Mourato. 2006. Cost-Benefit Analysis and the Environment: Recent developments. OECD publishing.

Richards J.A., R. J. Nicholls. 2009. Impacts of climate change in costal systems in Europe. PESETA-coastal systems study. EUR 24130 EN, JRC, European Communities.

Ramsey, F.P., 1928. A mathematical theory of saving. The Economic Journal 38, 543–559.

Rosenzweig C and Tubiello F. 2007. Metrics for Assessing the Economic Benefits of Climate Change Policies in Agriculture. Organisation for Economic Co-operation and Development: Paris.

Stern N. 2007. The Economics of Climate Change: The Stern Review. Cambridge: Cambridge University Press.

Stöckle, C.O., M. Donatelli and R. Nelson. 2003 CropSyst, a cropping systems simulation model. European. Journal of Agronomy 18: 289-307.

Swart, R., L. Bernstein, M-H Duong and A. Petersen (2008): Agreeing to disagree: Uncertainty management in assessing climate change, impacts and responses by the IPCC, Climatic Change (published on line).

Tol R.S.J. (2005), The Marginal Damage Costs Of Carbon Dioxide Emissions: An Assessment Of The Uncertainties, Energy Policy 33 (16), 2064–2074.

Tol, R.S.J. 2008. The double trade-off between adaptation and mitigation for sea level rise: an application of fund. Mitigation and Adaptation strategies for global change 12: 741-753.

Tubiello, F.N., M. Donatelli, C. Rosenzweig, C.O. Stöckle. 2000. Effects of climate change and elevated CO2 on cropping systems: model predictions at two Italian locations. European. Journal of Agronomy 13: 179-189.

UNFCCC, 2010. Potential costs and benefits of adaptation options: a review of existing literature.

UK: Her Majesty's Treasury and Defra (United Kingdom). 2009. *Accounting for the Effects of Climate Change. Supplementary Green Book Guidance*. Available at <http://www.defra.gov.uk/environment/climate/documents/adaptation-guidance.pdf>.

USAID (United States Agency for International Development) 2007. Adapting to climate variability and change: a guidance manual for development planning. USAID and Stratus Consultancy, Washington.

Van Kooten, G.C. and E. H. Bulte. 2000. The economics of nature: managing biological assets. Blackwell publishers, Oxford, UK.

Van Ierland, E.C., 2010. Project proposal for "Tools for adaptation strategies" for the Knowledge for Climate Program in the Netherlands, Environmental Economics and Natural Resource Group, Wageningen University.

Weikard H.-P. and X. Zhu. 2005. Discounting and environmental quality: When should dual rates be used? *Economic modelling 23*: 868-878.

Zhu, X., J. van Ommeren and P. Rietveld. 2009. Indirect benefits of infrastructure improvement in the case of an imperfect labor market. *Transport Research Part B (Methodological): 57-72*.