Technical Report D 2.4

# IMPROVED METHODS AND METRICS FOR ASSESSING IMPACTS, VULNERABILITY AND ADAPTATION

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# SUMMARY

Over the course of the MEDIATION project, Work Package 2 was tasked with "develop[ing] and apply[ing] a toolbox, defined as a set of models, methods, and metrics for the assessment of impacts and vulnerability and adaptation options." As highlighted in Deliverable 2.2, many frameworks and methods for assessing adaptation have been developed over the last 20 years, yet these often have not been adopted in the context of formal adaptation policies in Europe and elsewhere. Reasons and problems include: (i) a fragmentation of methods and tools, (ii) a lack of linkages to actual policy needs, (iii) a lack of understanding and communication of uncertainties, (iv) the often expert-based nature and complexity of methods used versus actual user demands, and (v) a lack of consistent data, definitions and metrics.

Deliverable 2.2 put forward a rough prototype for a toolbox of methods for studying impacts, vulnerability, and adaptation. In this deliverable, we discuss subsequent work on the MEDIATION toolbox, and report on application and testing of the improved methods and metrics in selected key European sectors and regions.

We present feedback and improvement to methods and metrics based on input from case studies, stakeholders, and focus groups, as well as an overview of case study work and contribution to an improved MEDIATION toolbox. This input resulted in a number of conclusions relating to the development and use of methods and metrics, reducing uncertainty in CCIAV, and led to a number of changes, including the creation of a novel typology for classifying methods and models relating to CCIAV analysis. We provide an overview of the new typology, as well as the final toolbox, and summarize case study contributions towards improved methods and metrics.

# INTRODUCTION AND OBJECTIVES

Work Package 2 of MEDIATION was tasked with developing and applying a toolbox of models, methods, and metrics, for the assessment of climate change impacts and vulnerability and adaptation options, with the end result being a toolkit contributing to the common platform. Deliverable 2.2 set out the first stages of work, developing and designing the toolbox and establishing a framework from which to proceed.

Initial work on a toolbox of methods was motivated by a number of research gaps, including: (i) fragmentation of methods and tools, (ii) lack of linkages to actual policy needs, (iii) lack of understanding and communication of uncertainties, (iv) expert-based nature and complexity of methods vs. user demands, (v) lack of consistent data, definitions and metrics. The toolbox was established with a goal of addressing these aspects and improving upon the state of the art via:

1. Better linking methods and metrics to relevant adaptation policy needs as voiced by stakeholders.
2. Better integrating the tools for impacts, vulnerability and adaptation assessment leading to a more consistent and systematic assessment. Integration may occur by means of one integrated tool/model, often it will mean composing a set of climate change impacts, adaptation and vulnerability (CCIAV) tools.

In light of discussions on the first iteration of the toolbox, common platform, and integrated methodology of the MEDIATION project, this Deliverable reports on the application and testing of the improved methods and metrics in selected European sectors and regions as developed through MEDIATION case studies. The toolbox of methods and models is put forward as a means of applying the outcomes of the iterative testing and application of the case study improvements in a number of manners, focusing on uncertainty, metrics, and an improvement of tools as well as scenario use. The following pages present work undertaken by Work Package 2 - following the original scoping of our work in Deliverable 2.1, where we propose the toolbox as a medium for presenting these improvements – as well as incorporating input from consortium members, case study stakeholders, and focus groups. Tools and methods are discussed at an individual level as well as the overarching framework of the toolbox, including linkages to the common platform and integrated methodology. As proposed in D2.1, the toolbox was seen as a final outcome of Work Package 2, and this deliverable should be viewed as a summary of conclusions relating to the development and use of methods and metrics relevant to CCIAV. The findings documented here relating to the treatment of uncertainty, organization of methods, as well as descriptions of both new and commonly used tools for CCIAV also contribute to the online toolbox portion of the common platform, describing the reasoning and motivations behind the iterative creation of the toolbox.

The report is organized as follows: Chapter 1 of the document first discusses individual case study contributions to improvements in CCIAV methods and models, focusing on the key issues listed above. The conclusions drawn from the cases motivate a number of improvements to the way methods and metrics are treated in CCIAV research, discussed in Chapter 2. Chapters 3 and 4 outline an improved typology of methods and models which builds upon previous work and provide a guide for structuring and organizing methods for climate change research, as well as provide a novel organizational scheme for the toolbox. Chapter 5 creates a synthesis of the preceding Chapters, and outlines the structure of the resulting MEDIATION toolbox; Chapter 6 proposes an Iterative Risk Management framework for use in future CCIAV analysis, also discussing conclusions and areas for further work. Appendix 1 consists of detailed descriptions of case study work, Appendix 2 contains the method and model typology used in the MEDIATION toolbox, and Appendix 3 provides individual tool descriptions for individual toolbox entries.

# 1 APPLICATION AND TESTING OF METHODS AND METRICS IN KEY EUROPEAN SECTORS

Task 2.4 is heavily reliant on case study outputs and resulting conclusions and improvements to methods are the result of case study work, stakeholder interaction, and frequent collaboration with other work packages, notably WPs 3 and 4. While cases were distributed amongst work packages for administrative purposes, they were cross-cutting in nature, as cases did not focus entirely on impacts and vulnerability versus economic assessment methods, etc. Additionally, case reporting for work package 4 and the integrated methodology had a large influence on a subsequent typology of methods and tools for task 2.4.

Cases focused on varying areas, both geographic and sectoral, with differing approaches and methods used. Each case has been documented with case study reports detailing the processes involved. A number of detailed case study reports are included in of this deliverable, and their contributions are discussed in-depth in below, but Section 2 also contains references to cases included in the Work Package 3 deliverable dealing with economic valuation methods, as they have also contributed to the key messages of this work. Cases and the locations of case descriptions are listed in the table below; we provide detailed reports on individual cases included in this document and their research activities in the following sections.

*Table 1. Summary of case studies and location of reports.*

| Case: | Location: |
|---|---|
| **EU Forest Fires** | D2.4 Section 1.1 and Appendix 1 |
| **EU Flooding** | D2.4 Section 1 |
| **Biodiversity in Northern Europe** | D3.5 |
| **The Elderly in Northern Europe** | D2.4 Section 1.2 and Appendix 1 |
| **The Rhine River in North-West Europe** | D2.4 Section 1.3 and Appendix 1 |
| **The Wadden Sea in North-West Europe** | D2.4 Section 1.4 and Appendix 1 |
| **Sea level rise in North-West Europe** | D3.5 |
| **Chianti wine in Tuscany** | D3.5 |
| **Heat and tourism in Tuscany** | D2.4 Section 1.5 |
| **Water stress and the Guadiana basin in Spain** | D3.5 |
| **The Guadalqivir basin in Spain** | D2.4 Section 1.6 and Appendix 1 |

All MEDIATION cases contributed to the development of the Toolbox via the use of specific methods, tools, and metrics, as well as testing of these via stakeholder interactions. Methods and tools used in MEDIATION are described in the toolbox, and are listed in Table 2 below.

*Table 2: Summary of tools used in final case study interactions and included in the MEDIATION toolbox. Note: Other Consortium and case study tools not used in the final analysis, but were highlighted for possible use are also provided in the Toolbox.*

| Case Study | Methods and tools used |
|---|---|
| **EU Forest Fires** | Community Land Model (CLM)<br>Simple Standalone Fire Model (SSFM) |
| **EU Flooding** | LISFLOOD |
| **Biodiversity in Northern Europe** | Stakeholder seminars and questionnaires<br>Bioclimactic Envelope Modeling<br>Cost-effectiveness analysis |
| **The Elderly in Northern Europe** | Stakeholder seminars<br>Trend extrapolation of adaptive capacity indicators<br>Mortality-temperature models<br>CARAVAN (Vulnerability mapping tool)<br>PEP |
| **The Rhine River in North-West Europe** | Coupled VIC-RBM Model<br>VIC and HBV Rhine Model<br>Semi-structured interviews |
| **The Wadden Sea in North-West Europe** | Expert interviews<br>Literature review |
| **Chianti wine in Tuscany** | Economic Impact Analysis<br>Grapevine Growth Model |
| **Water stress and the Guadiana basin in Spain** | Aquacrop<br>Economic optimization<br>MCA-AHP<br>Socio-institutional network mapping<br>WEAP |

Three of the cases listed in Table 1 fall under the coverage of deliverable 2.4, however were not developed to as large as a degree as others. They are discussed in sections below

The EU flooding case attempted to estimate future flooding impacts at a river basin level across the EU. The case planned to utilize two major components in its analysis, the LISFLOOD model, for estimating future risk of flooding at a basin level, and the CATSIM model, for impacts and vulnerability estimates at a national level.

The LISFLOOD model is a spatially explicit hydrological model that can be used for the study of climate change impacts to a catchment, as well as the forecasting of floods and assessment of river regulation policies. To assess future flood hazard, climate simulations from the ENSEMBLES project have been corrected for biases in temperature and precipitation by Dosio and Paruolo (2011) and Dosio et al, (2012). LISFLOOD simulations were performed in the framework of the ClimateCost project (Full Costs of ClimateChange, grant agreement 212774) with the final result being a high-resolution map of future flood hazards. (Rojas et al, 2012).The high resolution flood maps were not compatible with the CATSIM approach as the new GRID estimates were in higher spatial detail which did not correspond to input needs. Additionally, coding for the map clusters with a hierarchical convolution approach was not feasible as different maps were used for the LISFLOOD model compared to the CATSIM approach; again, the new data did not have the necessary structure required as input and it was not possible to reproduce the data due to time and computing power constraints.

Due to these constraints and an increased emphasis on the forest fire case and development of the SSFM, it was not possible to utilize these results for analysis within the CATSIM framework. However, this work will be continued within future projects (ENHANCE), and the process of developing the flood maps and attempting to derive estimates of vulnerability provided a valuable learning experience, and emphasized the need for model results that are not only detailed, but also have the ability to be interpreted and input into other tools; while the results of LISFLOOD are novel, time and computing power limitations relating to CATSIM rendered them unusable to the project, a lesson which should be taken forward and kept in mind when developing further tools.

The Tuscany case on tourism, focusing on heat stress and the tourism sector in Italy was discontinued to focus more extensively on the other Italian case on the impacts of climate change to the wine industry.

## 1.1 THE EU FOREST FIRE CASE

For the forest fires case study, objectives were twofold: 1) to set-up a modeling framework for the assessment of the forest fire risk in Europe, the regional release of $CO_2$ as consequence of forest fires, and changes in spatial pattern of fire risk level with respect to a range of climate change scenarios and policy options and 2) to include in the modeling scheme potential adaptation options discussed with relevant stakeholders.

A schematic diagram of the methodology followed to address the questions regarding adaptation options to forest fires in Europe is presented in Figure 1 (from Khabarov et al.,).

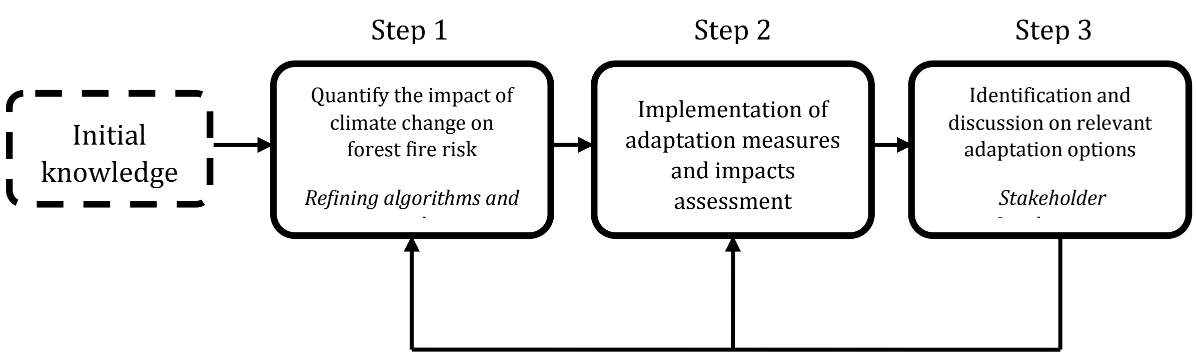



*Figure 1. Schematic diagram of the methodology followed to address the questions regarding adaptation options to forest fires in Europe.*

The diagram is intended to describe the adaptation learning cycle (Hinckel and Bisaro, 2013) applied in this case study, which comprises of three broad iterative steps needed for 1) projecting potential impacts; 2) projecting residual impacts of adaptation options, and 3) appraising and choosing adaptation options.

The latter step was carried out in consultations with forest fires expert and potential stakeholders during consultations organized for this purpose.

Step 1 focused on the assessment of potential impacts and consists of selecting, implementing, and refining of appropriate tools (i.e. models) to simulate the future potential impacts of climate change on fires occurrence and burned area at pan-European scale.

Step 2 focused on the choice of options and the assessment of the effectiveness of selected adaptation options to reduce burned area in Europe.

Step 3 focused on the discussion with sector experts and stakeholders on the results obtained in steps 1 and 2, with the main goal of sharing information about the estimated effectiveness of adaptation options, and sharing information useful for the development and improvement of our methodology. Steps 1, 2 and 3 are iterative, to refine the predicted impacts, reduce uncertainty and share information.

For this purpose we applied a widely used terrestrial biosphere model (Community Land Model, CLM) extended with a carbon-nitrogen biogeochemical model. Most of the updates of the model are described in (Lawrence et al. 2011).

The prognostic treatment of fires is based on the fire algorithm developed by (Arora and Boer 2005), modified and implemented within CLM by (S. Kloster et al. 2010). CLM includes both climatic and socio-economic drivers of forest fires, therefore, it allows the implementation of adaptation strategies in the model code. Because the tool was originally developed for application at global scale, in the context of MEDIATION FP7 Project we refined and calibrated the algorithm. More in detail, by using fires statistics reported in the European Fires Database (EFDB), developed in the context of the European Forest Fires Information System (EFFIS) (San-Miguel-Ayanz, Schulte, Schmuck, and Camia 2012), we calibrated the equations governing the relationship between anthropogenic ignition/suppression probability and population density. In this way we refined the description of the anthropogenic causes of fires in Europe.

Equations describing the spatial variability of fuel (i.e. biomass available for burning) were further refined according to the literature. The new formulation of the model was validated against independent satellite data and statistics of burned area (Migliavacca et al. 2013).

Results showed an improvement of both the temporal and spatial variability of burned area simulated in Europe by using the new model formulation (hereafter referred as CLM-AB). Moreover, it is demonstrated that the refined model was able to catch the complex interactions between burned area, climate, and fuel variability (Fig 2 from Migliavacca et al., 2013), and, therefore, can be consider a robust tool to simulate the future impacts of climate change on forest fires patterns in Europe.

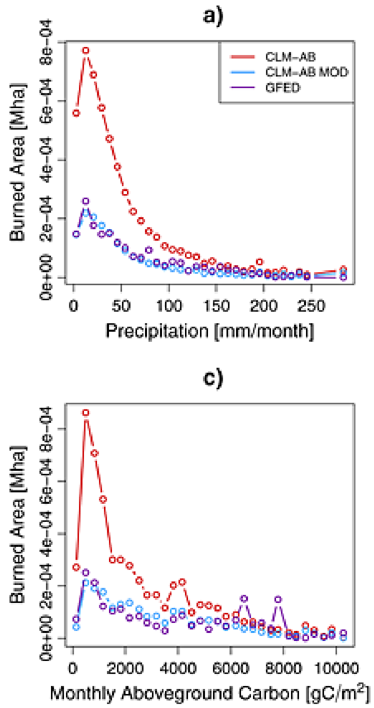



*Figure 2 – Relationship between Burned area, temperature, precipitation, and aboveground available carbon (soarse woody debris and litter pools). Burned area in bins of mean monthly temperature (a), precipitation (b) and aboveground biomass (c) according to CLM--AB (Original formulation, Red lines), CLM--AB (MOD: Improved formulation Blue lines) and GFED (Satellite observations Purple lines).*

One drawback of CLM-AB is the high demand of computing resources that might hamper the testing of a full range of adaptation options. For this reason a new tool was developed: a simplified stand-alone version of the CLM-AB model (further referred to as SFM). SFM model exists in two versions sharing the same source code. One version of SFM is in fact a CLM-AB's fire module decoupled from CLM-AB itself (further referred to as SFM-C), which aims at mimicking the CLM-AB's burned area output utilizing a subset of CLM-AB input and output variables (moisture, fuel biomass, and wind speed) that are external relative to the fire module itself. SFM-C provides faster computing time at the cost of losing the fire feedbacks to the biophysical part of the model. The other version further referred to as SFM-F is even more different from the CLM-AB. It is utilizing only datasets fully independent from CLM-AB (weather, biomass, population density) and does its own fuel moisture computation from the ground up, based on the Canadian fine fuel moisture code (FFMC) index (Van Wagner and Pickett 1985).

Based on the outcomes of the adaptation options identification and selection process, we implemented in the developed tool first the active suppression, and, second, prescribed burnings. The selected adaptation options represent two different approaches – prevention and reaction that are complementary to each other.

On the methodological side prescribed burnings were simulated by explicitly reducing available fuel biomass both in SFM-C and –F as a consequence of planned preventive fires.

Fire suppression is modeled through perturbation of a fire suppression parameter (namely, q). There are certain limitations in using the q as proxy of the suppression capacity, mainly resulting in difficulties to disentangle detection and response components, and other related factors e.g. setting up fire breaks. As a result, the current version of the tools only allows for sensitivity analysis of that aggregated proxy variable q rather than of more explicit indicators (e.g. time needed for detection). This limited approach is imposed by the model, yet it is a first pioneering attempt to quantify impacts of reactive and preventive adaptation strategies within one modeling framework at a large scale.

For further details on the case study, refer to Appendix 1, page 51.

## 1.2 THE ELDERLY IN NORTHERN EUROPE

Elderly people are known to be more vulnerable than the general population to a range of weather-related hazards such as heat waves, icy conditions and cold periods. In the Nordic region, some of these hazards are projected to change their frequency and intensity in the future, while at the same time strong increases are projected in the proportion of elderly in the population.

This case study reports results from three projects studying the potential impacts of climate change on elderly people in the Nordic region. The work comprised five analytical steps, with a research question posed at each step, and allowing for iteration to refine, reconsider or complement previous steps according to feedback from stakeholders and emerging new research questions.

A key outcome of the research is the development of an interactive web-based tool for mapping and combining indicators of climate change vulnerability of the elderly, by municipality, across the three Nordic countries: Finland, Norway and Sweden. The tool can also be used for projecting temperature-related mortality in Finland under different projections of future climate, and for depicting background information on possible adaptation measures for ameliorating the impacts of high temperature events.

The approach to vulnerability mapping differs from most previous studies in which researchers selected the indicators to combine into an index. Here, researchers compile data on key indicators that can be accessed in the mapping tool, but the onus is the users of the tool to decide which indicators are of interest, how to combine them into indices and how to interpret the mapped outcomes. Key stakeholders with responsibility for the care and welfare of the elderly were engaged in the study through interviews and a workshop. They affirmed the usefulness of the mapping tool for raising awareness about climate change as a potential risk factor for the elderly, and offered suggestions on how the prototype tool might be refined or extended. These included appending background information on alternative adaptation measures for ameliorating the impact of extreme temperatures, and improved representations of uncertainties in projections of future exposure and adaptive capacity.

The case study results also offer formulations for linking indicator studies of vulnerability with model-based studies of impacts, by expressing both in terms of exposure and sensitivity. These terms are then mediated by different representations of adaptation and of future socio- economic trends.

A complete case summary is available starting on page 70 of Appendix 1 of this document.

## 1.3 The Rhine river in western Europe

Climate studies show high probabilities of changing hydrological regimes in European rivers. Concerned authorities increasingly ask whether current management practices are able to cope with these changes or whether alternative management regimes are needed. This paper presents a case study on the Rhine river basin. The Rhine River basin was selected because numerous scientific publications provide a rich state of knowledge on possible consequences of climate change in the basin. The aim of the case study is to explore if, and when the current management regime will no longer be able to meet its objectives due to increasing frequencies of extreme low flow events. Thresholds in two management regimes are analysed: the program to reintroduce a sustainable population of Atlantic salmon and inland shipping between Rotterdam and the German Ruhrgebiet industrial area. Questions asked are: 1). When will thresholds in the management regime of inland shipping and salmon reintroduction be crossed under pressure of changing low flow conditions? 2). What management options exist to avoid threshold crossing? 3). What are assumptions and methods used in the threshold assessment approach?

The complete case is documented in detail in Appendix 1, page 94.

## 1.4 The Wadden sea in north-west Europe

There is a demand for methods and tools to assess and communicate the implications of climate change for decision-making. Concerned decision makers increasingly pose questions as to whether current management practices are able to cope with climate change and increased climate variability or whether alternative strategies are needed. They urgently demand reliable science-based information to help them respond to climate change impacts and opportunities for adaptation (Dessai *et al.*, 2004). The linking of science with user needs is a multifaceted problem with no simple solutions.

Many different tools and methods exist to structure the process of providing decision support. This paper aims to analyze the adaptation decision-making process in the Dutch Delta Programme for the Wadden region as a case for the diagnostic framework. The Delta Programme is currently being designed to protect the Netherlands from flooding and to ensure adequate supplies of freshwater in the prospect of climate change (Delta Commissioner, 2011). As an example of adaptation decision-making it offers an attractive case to reflect on tools and methods used in practice. In particular this paper focuses on the knowledge questions addressed during the first three years of the decision-making process, and the associated tools and methods. It will re-narrate this process using the steps and decision trees in the diagnostic framework and will reflect on reasons to divert from the diagnostic framework. To do so, we will follow the steps and decision trees of the ATN.

The use of methods in the adaptation planning process can be explained quite well by the decision trees of the MEDIATION diagnostic framework. Diversions occur when the selection of tools is informed by practical limitations of the decision making process, such as available resources and experience of the involved experts.

Further information documenting the case steps and conclusions of the case study can be found in Appendix 1 (page 108).

## 1.5 IMPACTS OF CLIMATE CHANGE ON TOURISM IN TUSCANY

The case study is aimed at assessing the impacts of climate change on tourism and health in Tuscany, and to draw possible adaptation options to cope with these.

The results of the assessment as regards health are available in the scientific paper "Air temperature-related human health outcomes: Current impact and estimations of future risks in Central Italy", Morabito et al. 2012 (doi 10.1016/j.scitotenv.2012.09.056).

The main idea, given the knowledge and expertise of the three main groups involved, was to build a model able to explain the influence of climate on tourism, both directly (e.g. the negative effects of rainfall on the touristic flows of the 25th April – 1st May holiday period) and indirectly (e.g. higher prices of camping due to increased water cost in a drier hypothetical climatic scenario), in Tuscany. This would be accomplished by exploring different time scales (from annual and seasonal, to more detailed periods, such as week ends), spatial resolutions (from regional to municipality), touristic types (such as sea or mountain), and different bio-climatic indicators (temperature, humidity, hot days, heat waves). Once the model is created, tested, calibrated and validated, it could be applied to other European regions. This support tool could be a valuable help for local administrations, touristic sector associations, and for all the stakeholders aiming at planning the development of the sector on the long term including climate and its changes as well.

All the groups involved were interested on the topic, and agreed to invest in a preliminary study aimed at identifying the relations between observed climate in the Tuscany Region during the last 15 years, and the touristic fluxes of the same period.

Given the strong link between the "real world" and the Center for Touristic Studies of Florence (CSTF), which is preparing and analysing the statistical data of the touristic sector in Tuscany – thus having a deep knowledge of the sector and its dynamics, and is dealing with touristic sector operators at all level in the region, it has been decided to start an empirical study, and to focus on operational outputs of the study itself to be used by stakeholders.

A first assumption to be checked was that the scale is important in the study, and that at regional level the climate is influencing marginally the touristic fluxes; a subsequent assumption to be checked was that at local level (municipality or territory), given a specific season and main touristic type of the study area, the climate may have significant impacts on touristic fluxes, at least important enough to be included in long term planning.

For this first assessment, a case study including 8 coastal municipalities of Maremma (South-Western Tuscany), dealing mainly with seaside tourism, was set up. In particular, the municipalities of Capalbio, Castiglione della Pescaia, Follonica, Grosseto, Magliano in Toscana, Monte Argentario, Orbetello and Scarlino were chosen.

In order to carry out the study, the Il Dipartimento di Progettazione e Studio dell'Architettura (The Department of Architecture and Design at the University of Rome, or DiPSA) provided an extensive dataset with observed, interpolated meteorological data, at high both spatial and temporal resolution, for the study area from 1996 to 2011.

### 1.5.1 Analysis

A first analysis on possible relations between climatic variables and touristic fluxes has been carried out on annual data, and produced negative results; that is, no relationships could be observed.

The seasonality of the fluxes in the 15 years showed an increase, with higher concentration of the demand during the high season. A general growth could be observed, not related to climate and therefore likely associated with other factors, not included in the present study, such as the economic situation, changes in prices (offer), and others not easily detectable.

By switching to monthly data, it was possible to study seasonally adjusted data (that is without the bias due to the seasonality). Furthermore, since the study area showed an increasing trend of fluxes, it was possible to correct the data, removing the trend itself. The corrected data were studied, in order to find possible relationships with climatic data.

First analysis was carried out on January, low season for the study area. With some exceptions, no relation was found between arrivals and climate. (Pearson index found to be negative but almost zero). This was also confirmed by studying only the arrivals in hotels: with the same climatic conditions, the Pearson index was positive, but still close to zero.

The analysis performed on the month of April (excluding however the years in which Eastern did not occur in this month) produced the only interesting result. It seems that, during a "transition" month, from winter to spring and summer, with long weekends and some holiday period, the (favorable) climatic conditions play an important role in the choice of travelling, both for Italians and foreigner tourists. As a matter of fact, for the April a -0.8 correlation index was found between arrivals and cumulated rainfall, while a -0.7 was found between cumulated monthly rainy days and arrivals. As expected, the correlation is lower for hotels (-0.5 correlation between rainfall and arrivals) than for other type of accommodations (-0.8). Some correlation could be found for temperatures as well.

The analysis of the data of the month of May, even if is still another transition month, with a long week-end, the relations found are again marginal, with only two significant variables: temperatures and rainy days. Similar correlations were found for July, only for the temperatures, which have a larger effect on Italian demand and much less on the foreign one.

The first study suggests small, sporadic correlations between the climate and the tourism at monthly level, which were not found at annual level. This could mean that an unfavorable weather is likely to negatively affect the choice of travelling, thus potentially decreasing potential tourists; however, if there are no changes in income and free time to be spent, the trip is likely to be just postponed to a more favorable period, thus not affecting the general picture. This could explain how the correlation tends to be lower and lower, to null, from monthly to seasonal and annual scale.

### 1.5.2 Conclusions

This preliminary study does not allow identification of relationships between climate and touristic fluxes useful for the assessment of the impacts of climate change on tourism. More complex analysis, with the use of different tools for the statistical analysis or classification systems, the inclusion of other variables to exclude other factors determining the trends (such as the economic situation, the country of origin, international and national ordinary and extra-ordinary events and holidays, etc.), and more detailed and longer time series to be studied, may all help in a better understanding of the relationships between climate and tourism, and provide a basis for the assessment of climate change on touristic sector.

## 1.6 Adaptation in the Guadalquivir Basin

Given the importance of agriculture for the local economy and the vulnerability of the sector against climatic variations, the Government of Andalusia initiated its *Strategy against Climate Change*[1] as early as in 2002. This initiative was the first of its kind in Spain. Besides this document, the Government of Andalusia sanctioned on June 5th 2007 the *Andalusian Plan of Action for Climate 2007-2012: Mitigation Plan*. The objective of the program was to reduce 19% of all greenhouse gas emissions in Andalusia by 2012.

On August 3rd 2010, the regional Government sanctioned a new Plan, the Andalusian Climate Change Adaptation Program[2], which aims to minimize the negative effects of climate change in the Andalusian region. The Program is again divided into several interrelated subprograms that set the steps to be followed in a more precise way. These subprograms are:

- **Subprogram 1:** Definition of immediate measures aimed to promote efficient energy use, improve water management, prevent soil erosion and preserve biodiversity.

- **Subprogram 2:** Sector analysis on the effects of climate change, measuring impacts and adaptation measures in the following sectors: water, energy, soil, forests, biodiversity, health, agriculture, tourism sector, transports and land management.

- **Subprogram 3:** Define sector oriented adaptation measures following information generated in previous subprograms. This step resulted in a series of reports[3] developed by Andalusian Government's sectoral offices that contained specific adaptation options for their area of expertise (see summary for Agriculture and Water Sectors in Annex 1)

Drawing from these reports and the specific measures they contain, as well as discussions with selected stakeholders (Director of a Farm Management Firm, Spanish Climate Change office, Environmental Group representative, researchers) the research team started the design of an Analytical Hierarchical Process (AHP) exercise aimed to prioritize different adaptation options for the agricultural sector in the Guadalquivir basin.

Further detailed information on this case study can be found in Appendix 1, page 124.

[1] Estrategia Andaluza ante el Cambio Climático, available at Portal Andaluz del Cambio Climático
[2] Programa Andaluz de Adaptación al Cambio Climático, available at Portal Andaluz del Cambio Climático
[3] These reports are available online at Junta de Andalucia's website

# 2 Key outputs of case study testing and implications for the MEDIATION toolbox

The following Chapter highlights key results from MEDIATION case studies in areas related to improved methods and metrics for CCIAV analysis.

## 2.1 Increasing emphasis on uncertainty and robustness

A major component of CCIAV research addressed in the MEDIATION Description of Work is a focus on representing model, data and aleatoric uncertainties and working towards robust analyses, which was assessed by Work Package 1 Deliverable 4.1 as well as individual case studies. D4.1 highlights three simple themes to focus on when addressing uncertainty in scientific research: parsimony, personalization, and practicality. The Tuscan wine, forest fire, Guadiana, and biodiversity cases each addressed these themes during the course of stakeholder workshops, and the three points are discussed below.

### 2.1.1 Parsimony

D4.1 defines parsimony as the idea of providing policymakers and stakeholders with the proper amount of information ("Less is more, but more is not less"). The idea is that if provided with too much information, policymakers may outright ignore all of it; when framing information as highly uncertain, they may not be moved to take any action, effectively ignoring it.

The Tuscany wine case experienced the above problems; in a stakeholder workshop, tools from the MEDIATION toolbox were used to present initial results to participants both before and during the meeting. The case found that there existed a certain degree of fear within stakeholders due to uncertainties bound to climate projections and intrinsic constraints of the wine sector. To address these concerns, the case focused on assessing uncertainty via the use of an ensembles approach to provide a range of estimates for future scenarios (as recommended in D4.1) as well as to more closely involve stakeholders in subsequent analysis via the use of a decision support tool (AHP). This approach enabled the case to provide more useable and concise information and provided decision-makers with the opportunity to learn more via subsequent workshops and involvement via AHP.

The EU forest fire case also focused on the need for parsimony in stakeholder interaction; in feedback from an initial stakeholder meeting, there was a degree of debate and skepticism about the simplification of processes description into the tools used. There was a certain degree of concern about the accuracy of the description of processes in the tools used (e.g. models). They agreed that a certain level of simplification is necessary in particular for studying impacts, vulnerability and adaptation strategies at European scale because otherwise the lack of information would be increase the uncertainty of methods and tools proposed. The meeting concluded with the idea that the concept of scale at which methods and tools could be applied should be stressed in order to clarify at the end-user the range of applicability of methods and tools.

### 2.1.2 Personalization

Personalization as used in D4.1 refers to the need for personalizing and humanizing the information given to stakeholders to improve communication of results. When information is linked to a story or human emotion, decision-makers are more easily able to keep that information in their minds and recall / use it for decisionmaking. The Northern Europe biodiversity case highlighted the usefulness of this concept via stakeholder surveys.

Work on the northern biodiversity case was dual faceted, with research on both species mapping and estimates of future distributions, as well as stakeholder inputs on possible adaptation measures. After a workshop in September of 2011, a survey was distributed to 8 participants, with two questions of importance pertaining to improving metrics. The first asked, “What kind of research do we need about the effects of climate change and adaptation to climate change?” Responses varied, but there was an emphasis on having more information that “aims for practical / hands on action”, “tailored for Finland’s circumstances”, which would “find out the concrete threats and opportunities.” Other responses included a desire for more economic oriented analysis, improved understanding of how land use and other variables affect species, and a general increase in modeling. In another question, asking what methods should be used to evaluate the effects of climate change on biodiversity, increased monitoring was put forward by almost all respondents in some form, whether it is monitoring change in farmer’s economic success, climate variables, or indicator species levels.

### 2.1.3 Practicality

Practicality as an organizing concept here emphasizes the need for providing stakeholders with the best possible results and information in a way that best fits the stakeholders’ decision-making framework. D4.1 emphasizes the need to provide stakeholders with the information they need, as well as the possibility to investigate alternative approaches and methods, giving them the ability to learn about other possible frameworks for their problem.

The Guadiana basin case study addressed issues of practicality as discussed in D4.1 in the context of their stakeholder interactions. In January 2012, the case study researchers met with stakeholders to discuss presentation of results from the SCENES project and model results from UPM in the Guadiana basin using differing modeling approaches, as well as development of a social network mapping exercise with stakeholder participation, to analyze the actors involved in the region. An evaluation questionnaire distributed after the meeting enabled stakeholders to provide input on the models used, the previous participatory meetings, and the social network mapping.

The stakeholder survey allowed for evaluation of the different modeling approaches used in the case study in four categories: (1) the usefulness of the model for the river basin management, (2) the capacity of the model to represent reality, (3) the consistency of results, and (3) the generation of knowledge.  Case study partners found that the valuation of models was directly correlated to the time employed in the explanation of the respective models, and can make us deduce that the higher effort to make stakeholders understand the functioning of a model, the higher consideration they gain of that model. They also concluded that stakeholders attach a high importance to the usefulness of the models for improving the system's learning and facilitating the basin's management over the perfect representation of reality.

In response to being asked how a toolbox could best be improved to better meet stakeholder needs, they replied that they are most happy when not only one type of model, but a set of tools is available for the basin. They expressed their satisfaction with having several complementary models which provide details on different aspects of the system. They seemed especially interested in having data and tools related to climate change, which can help them understand potential impacts in the basin and possible adaptation strategies. It is relevant to note that, in the survey, the social network mapping exercise was marked 7.5, at the same level as the most valued models, and that all of them expressed their interest in continuing their participation in future MEDIATION meetings.

In our view, the availability of a toolbox of methods is a key element to foster stakeholder interest on the project and it would be necessary to work on the dissemination of those tools, making them understandable by policymakers and, in general, by stakeholders.

### 2.1.4 Conclusions

Corresponding to Deliverable 4.1, we found through experiences with individual case studies that a range of strategies are needed to reduce uncertainty, focusing on parsimony (providing the right amount of useful information), personalization (creating a personal story and experiences behind the research and creating something more memorable for policymakers than just sterile and unconnected presentation of results) and practicality (providing the best possible results to fit a decision-making framework, but also provide the opportunity to look into other ways of doing things). The development of the MEDIATION Toolbox incorporates the above messages, and tries to address all three facets of reducing uncertainty; the approach taken to achieve this is presented in Chapter 2.1 and 2.3.

## 2.2 IMPROVING TOOLS

While cases contributed to the toolbox of improved methods implicitly two cases in particular explicitly improved upon or created new models to assess climate change impacts and vulnerabilities. The EU forest fire case developed a standalone forest fire model to better test impacts of various adaptation options, the Nordic case on adaptation of the elderly developed a web tool to assess vulnerability and adaptive capacity; all cases are discussed below.

### 2.2.1 EU forest fire case

The EU fire case linked outputs of the Community Land Model (CLM – for more information, see entry in Appendix II) with a new model developed by JRC and IIASA to test impacts of various adaptation options. The CLM model, part of a larger suite which models changes in climate based on the interaction of physical, chemical, and biological processes in the atmosphere, oceans, and land surface, allows for numerous modeling possibilities; a novel version of CLM including the description of fires (Kloster et al 2010) is used by the EU Forest Fire case study to model future areas at risk of fires, the temporal variability of burned area and possible adaptation measures to reduce risk.

CLM outputs were utilized by the simplified stand-alone fire model (SSFM) developed by JRC and IIASA researchers. SFM, a model based on the fire routine implemented in the Community Land Model (Kloster et al., 2010), was developed to test the impacts of different adaptation options. SFM-C provides faster computing time at the cost of losing the fire feedbacks to the biophysical part of the model. Within the framework of the SFM algorithm two adaptation options strategies are currently implemented: 1) modeling of active suppression and 2) prescribed burnings

The SFM might be used to simulate future patterns of fires probability and burned area, as well as for the analysis of the impacts of prescribed burning and enhancement of fires suppressions at pan-European scale. SFM improves upon the current state of the art by providing high flexibility for testing adaptation options with low computational ability, and by including adaptation options into the previously existing modeling framework.

For a complete description of the forest fire case and the SSFM, a complete case overview is provided in Appendix I.

### 2.2.2 The CARAVAN Tool in Northern Europe

The Nordic case study on vulnerability of the elderly to periods of extreme heat and cold. To assess vulnerability and adaptive capacity at municipal levels, the case developed the CARAVAN (Climate change: a regional assessment of vulnerability and adaptive capacity for the Nordic countries) vulnerability mapping tool; an online resource designed to help users explore different aspects of vulnerability to climate change in the Nordic region. Indicators of exposure to climate change, the sensitivity to these changes and the adaptive capacity to cope with these changes are captured in a geographically detailed web-based tool that allows interactive mapping of combinations of indicators into indices of vulnerability. The tool is designed to allow users to explore these aspects (e.g. by selecting indicators of interest, mapping them alone, weighting them, combining them, and/or looking at them in conjunction with exposure indicators under different climate scenarios), rather than predefining the factors that influence vulnerability. The vulnerability mapping tool covers to two themes, vulnerability of the elderly and agriculture, and is available via website.

### 2.2.3 Conclusions

While there already exists an abundance of tools for assessing climate change impacts and vulnerabilities, as discussed in MEDIATION Deliverables 2.1 and 2.2, the above cases emphasize that there remains further gaps to be filled or improvements to be made upon the state of the art. Case studies highlighted gaps in the current catalogue of tools in the toolbox, as well as tools missing from research more generally. The results of the cases, building upon D2.2 and work in WP4, drove the creation of an improved typology of methods and tools for climate change adaptation research, which is discussed further in Chapter 3.

## 2.3 SCENARIO AND PROBABILISTIC ANALYSIS

While Chapter 3.1 explicitly addresses the treatment of uncertainty by case studies, there were further implicit efforts to tackle data and modeling uncertainties via the use of scenarios and probabilistic estimates. The CLIMSAVE project, a corresponding FP 7 research project, deals extensively with the use of scenarios and derives a number of notable points. Within MEDIATION most cases utilized standard scenarios such as those provided by the IPCC SRES and ENSEMBES simulations. Taking another approach, the EU flooding case utilized probabilistic methods to reduce uncertainty. Both instances are discussed below.

### 2.3.1 The use of scenarios

While to a certain extent, the use of scenarios in MEDIATION case studies was limited mostly to the use of IPCC SRES or ENSEMBLES datasets for estimates of future climate, the CLIMSAVE project notably producing quite some work dealing with scenario creation, specifically a “Report on the new methodology for scenario analysis” (Kok et al 2011). The CLIMSAVE work emphasized the need for a participatory approach to scenario-building and while the process was not perfect, it was concluded that scenario construction with stakeholders was successful, mainly that stakeholder participation can be useful in improving their confidence in the models (see Chapter 3.1.3 above) and involvement of stakeholders in the project, as well as providing a link between models and the scenario via the use of fuzzy sets.

First used in the SCENES project, fuzzy sets allow for stakeholders to directly estimate the values of model parameters during a participatory scenario-writing process and thus set variables of interest in the scenario/storyline process. However, the process is not without its drawbacks. Notably, with increasing scenario or model complexity, the time demanded of stakeholders increases, as well as the number and specializations of participants required to create the scenarios. At a European level, this becomes very difficult, as the personal stake involved is weak compared to local or regional levels. Additionally, iterative storyline creation with stakeholders is difficult, and both stories and model inputs and outputs change with every iteration. On the plus side, changes become smaller over time, hinting at equilibrium input values between stakeholders and researchers (Kok et al, 2011).

The CLIMSAVE approach to scenarios was unique for their project, as the final output is an integrated assessment model for Europe assessing future impacts and adaptation to climate change over a wide variety of sectors. Given the self-contained manner of the CLIMSAVE tool, a set of independently-created scenarios via stakeholder participation is justifiable, but may not translate adequately as an example for MEDIATION work, which consists of a diverse array of cases, not only in terms of sectors assessed, but also spatial scope, assessment methods, final metrics, etc. Cases in MEDIATION predominately used a set of scenarios taken from the IPCC’s Special Report on Emissions Scenarios, with limited stakeholder involvement in determining socio-economic scenario parameters. While the scenarios used are not tailored to the regions of study as exactly as storylines developed via participatory approaches, using SRES scenarios still allows for a number of possible future pathways to be represented by case study research, and by utilizing well known emissions scenarios, allows for comparison between the resulting indicators, which could prove difficult given the same methods applied to a different set of initial scenarios leading to an entirely different set of outcomes.

### 2.3.2 Probabilistic analysis

Likelihood or probability of extremes is another key input for estimating risk. The analysis of weather extremes and adaptation to their impacts is complicated by the inherent aleatoric (“chance”) uncertainty of these phenomena. Although specific climate-related extremes are unpredictable beyond a few days in the future, they are predictable in probabilistic terms, such as the 100 year flood (an event with an average recurrence period of 100 years, or an annual probability of 1%) with natural disaster risk commonly defined as the probability of potential impacts affecting people, assets or the environment.

There is a wealth of information available on hazards, less so on their probability occurrence in terms of information on climate variability. Climate projections using multi-model ensembles show increases in globally averaged mean water vapor and precipitation over the 21st century. Yet, precipitation scenarios show strong regional differences. In Europe, there is a marked contrast between predicted future winter and summer precipitation change in Europe. Wetter winters are predicted throughout the continent (in many places – less snow and much rain), while in summer, a strong difference in precipitation change between northern Europe (getting wetter) and southern Europe (getting drier) is projected.

The EU flooding case attempted to address the discrepancy between mean values and probabilistic estimates via the estimation of 100 year flood hazard levels. An estimate such as this provides a clearer picture into potential future scenarios, and is a much better descriptor of a sudden onset event such as flooding than an estimate of annualized losses.

### 2.3.3 Conclusions

While there was not one single message to emerge regarding the use of scenarios and probabilistic estimates, cases use different approaches with the same objective of reducing uncertainty. Whether that is via the use of an ensembles approach and multiple scenarios of future values or via probabilistic analysis, the goal is to work towards parsimony, supplying policymakers and stakeholders with estimates that represent ranges of future values. Each approach towards uncertainty reduction via scenarios or probabilities has its own strengths and weaknesses; fuzzy sets work best at local or sub-national levels, and iterative storyline creation is time consuming, costly, and may be difficult to carry out with a large number of stakeholders. Conversely, probabilistic estimates may be a useful tool for describing potential future changes, but information on hazard event occurrence is currently lacking, and the production of new spatially-explicit hazard estimates can be costly and time consuming, as was the result in the EU Flooding case.

## 2.4 Improving Metrics

Metrics, or indicators, as defined by the EC's 2009 White Paper on Adaptation, are designed to "build a structured information dataset to better understand the territorial and sectoral distribution of vulnerability to climate change impacts (EC, 2009)". The EEA report on Impacts and Vulnerability in Europe (2012) provides a number of guidelines pertaining to selection of indicators, grouped into categories such as: (i) policy relevance, (ii) causal links to climate change, (iii) methodological and data quality and accessibility, (iv) robustness and known certainty, and (v) acceptance and intelligibility (EEA 2012).

The EEA and other EU bodies maintain an impressive list of indicators, though it should be noted that EU indicators do not explicitly take climate change into account. The EEA's dataset includes a number of indicators relevant to climate change, impacts, and vulnerability. MEDIATION case studies have in some cases produced outputs which are comparable to EEA's datasets, whereas in others, outputs are markedly different. Many EEA and EU indicators are at a much higher spatial resolution than the results of the project's case studies, which commonly focus on much smaller regions, such as basin-level analysis. However, in the pan-EU cases (fire and flooding) the indicators produced in MEDIATION are directly comparable (see Table 2 below).

*Table 3. Selected case studies and corresponding metrics from EEA and MEDIATION*

| Case study | Presumed EEA Indicator(s) of relevance (Source: EEA, 2013) | MEDIATION indicator |
|---|---|---|
| **Forest fires** | Burnt area | Burnt area |
| **Flooding** | River flow, losses from flooding | River flow, losses from flooding |
| **Rhine River** | River flow | Management regime thresholds |
| **Wadden sea** | Storm surges, floods and health, global and European sea level rise | Adaptation tipping points |
| **Finland Biodiversity** | Plant, insect, and animal population distributions | Butterfly population distribution |
| **Guadiana Basin** | Irrigation water requirements, water-limited crop productivity, growing season for agricultural crops, crop yields | Changes in crop yields, changes in crop water demands, unmet irrigation water demand |
| **Tuscany wine case** | Crop yields, water-limited crop productivity | Changes in wine crop yields, changes in projected income with / without adaptation |
| **Vulnerability of the Nordic elderly** | Temperature-mortality relationships | Municipal spatially-explicit vulnerability to heat and cold extremes |

As can be seen in Table 2, suggested indicators from the EEA do not in all cases match those of MEDIATION case studies. For large, pan EU cases, results are very similar to current indicators, however, these large scale indicator sets are markedly different that the output indicators for cases such as the Rhine river or Wadden sea, as discussed below.

### 2.4.1 Thresholds and tipping points in the Rhine river basin

There is a growing tendency in science to identify and communicate thresholds and tipping points in physical and in social systems forced by climate change (Werners et al. 2013). Lenton et al. (2008:730) identify potential tipping points in earth's system (like the Arctic sea-ice and the Greenland ice sheet) and express the hope that communication of these threats will influence climate policy (Lenton et al. 2008. P. 1792). In their analysis of the use of climate tipping points and thresholds -both in scientific and in public discourse- Russill and Nyssa (2009) recognize the use of the terms as a means to raise alarm and to attract political attention (Russill and Nyssa 2009). They warn however for unexpected and unwanted effects of such communications (increasing political apathy for instance) and recommend to be more clear and explicit on what is exactly communicated.

In the Netherlands researchers use tipping point analysis to inform planning of adaptation strategies (Walker et al. 2013). Kwadijk et al. (2010) define an adaptation tipping point as the moment when the extent of the impacts of climate change is such that "*the current management strategy will no longer be able to meet the objectives*" (Kwadijk et al. 2010:730). The identification of future climate induced policy failure will communicate the urgency (or the lack of urgency) of adaptive action and forms a basis for assessments of priority in actions. Werners et al. (2012) use a broader definition of threshold to include social preferences, stakes and interests. An adaptation turning point is defined as: "*a moment when a socio-political threshold is reached, due to climate change induced changes in the biophysical system*"(Werners et al. 2012:3).

Both approaches assume a future change in a management regime forced by impacts of climate change. The understanding of the management regime however differs. Kwadijk et al. (2010) predominantly focus on formal policies, often institutionalized in legal standards, while Werners et al. (2012) takes a broader open governance approach to management regimes and uses turning points to indicate that policy thresholds are not crossed at once, but go through a period of reframing and discussion, before the regime shifts toward a new state (Werners et al. 2012).

This case study applies the adaptation tipping or turning point approach in the Rhine river basin. Since climate change became an issue, the potential impacts on the Rhine hydrological regime have been subject of study of several research projects and scientific publications (see Middelkoop et al. 2001; Middelkoop and Kwadijk 2001; Barnett et al. 2005; Te Linde 2006; Görgen et al. 2010; van Pelt and Swart 2011; Te Linde et al. 2012). Most of this research was directed at floods and as a result adaptation strategies for flood security infrastructure are being developed. However, the need to anticipate with changes in low flow events has received insufficient attention.

The aim of the research is two-fold: the first is to identify thresholds in water management regimes forced by projected increases in frequencies of extreme low flow events and possible adaptation options in the Rhine river. We claim that finding thresholds in water management regimes will allow us to assess the urgency for managers to take decisions on adaptive action. In defining a threshold we will adopt the definition proposed by Russill and Nyssa (2009): a threshold is *"a shift from one identifiable regime to another at an identifiable point without entailing rapid change"* (Russill and Nyssa 2009:343). The 'identifiable regime' in this case study is a river management regime which aims at making use of river water for the purpose of a sector or a policy process.

### 2.4.2 Adaptation turning points in the Wadden sea

Due to climate change, conservation may no longer be the sustainable option and sustainability will have to shift its attention to adaptation and strengthening resilience in social-ecological systems. This requires long-term planning in the face of uncertainty. Threshold behaviour in particular adds to the adaptation challenge in complex systems.

Socio-political thresholds, such as those defined by policy objectives or stakeholder acceptance, provide an important entry point for a dialogue between science and policy about *why* people care, *how much* stress a system can absorb before an unacceptable situation is reached, *when* this is likely to happen, and *what* can be done, i.e. how sustain conditions for social-environmental activities in the face of uncertainty and change.

Case studies show that the assessment of social-political thresholds, tipping and turning points can produce information that is legitimate, salient and credible for decision-making. Salience is derived from focusing on actor concerns and in particular what actors define as unacceptable change. Legitimacy stems from the central position that the concerns and values of actors take in the assessment. In addition legitimacy results from facilitating the discourse around potential changes in objectives and responsibilities. Adaptation governance has an important role to play in the definition and renegotiation of rules and policy objectives untenable under climate change. Credibility results from combining bottom-up elicited social-political preferences with the top-down impact projections to assess when and how likely it is that unacceptable conditions occur. Making this link between actor values, policy objectives and projections of global change is one of the most challenging aspects of the assessment as multiple links often have to be considered and transient scenario runs at an appropriate scale are scarce. Thus there may be a trade-off between the complexity of the socio-political concern (salience) and the accuracy and scientific rigor that can be achieved (credibility) as presently the impact of climate change on more complex social-ecological systems and policy objectives is poorly understood.

Finally, the identification of thresholds helps in mapping practical adaptation pathways that pull together information on available options and path-dependencies. These encourage taking the necessary short-term actions to sustain the current system, whilst keeping options open for planning longer-term activities and more fundamental system change that may be required depending on how time unfolds.

Concluding, it is the combination of scientific underpinning and practical application that we feel makes a focus on thresholds, turning points and adaptation pathways attractive for furthering sustainability under climate change.

### 2.4.3 A final word on metrics

The above sections speak to the need for policy relevant metrics that are readily acceptable and understandable by stakeholders and policymakers, and further confirm the approach to metrics as extremely context-specific. However, such focused indicators provides specificity at a very focused level while sacrificing an ability to make comparisons between individual case studies, a task more easily achieved by use of common metrics. While these trade-offs each provide benefits, the stated goal of the project and work package is to develop improved methods and metrics for CCIAV analysis; an aim more in line with context-specific and applicable metrics rather than a broad set of commensurable indicators which may be of less eventual use to policymakers and stakeholders. Results from MEDIATION cases highlights that indicators may meet the conceptual criterion spelled out by such authorities as the EEA, having policy relevance, links to climate change, while striving for robustness and reducing uncertainty and being easily accessible, while at the same time being unique to the research question or adaptation problem at hand.

# 3 IMPROVING METHODS AND TOOLS BASED ON CASE STUDY RESULTS

The previous Chapter, while focusing on individual case study approaches to uncertainty, improved methods and metrics, and usage of scenarios, has great relevance to the methods and models for climate change adaptation as a whole, and also motivated a final iteration of changes to the MEDIATION toolbox, to better address uncertainty, the selection of tools to be used, and the quality and relevance of information provided for users.

## 3.1 UNCERTAINTY

Three of the cases emphasized stakeholders' desire to better address uncertainty, making this the most visible issue to be addressed by a second stage of the toolbox. Both the Tuscany and EU fires case indicated a level of apprehension and skepticism from the stakeholders regarding model outputs and uncertainty, which could effectively be addressed by changes to the toolbox and how information is conveyed. The Guadiana case also points to a need to improve how uncertainty is approached by referencing how increased awareness of the tools leads to an increased trust. Stakeholders favored models that were given the lengthiest overviews over more unfamiliar methods, indicating a need to more effectively convey information about tools in the toolbox, and ensure an even "coverage" of tool descriptions.

One of the goals of Work Package 2, defined in the Description of Work, was to address uncertainties in IVA analyses, which was to be achieved through creation of a toolbox with relevant information about key tools being presented in a standardized, clear format. While this has been accomplished, the WP 4 Deliverable on uncertainty highlighted another possible avenue to address this problem, namely by having experts convey, in simple terms, important information about the strengths and weaknesses of individual methods. This was achieved in the toolbox by the inclusion of "Strengths" and "Weaknesses" categories, added to the description of each item, written by experts familiar with the tools (preferably from the case study teams) in language that is clear, frank, and relatively simple / conversational, as is recommended in D 4.1.

Case studies were asked to provide this input for each tool used in the final case analysis and provide a clear step towards reducing uncertainties based on the criteria from D4.1. MEDIATION tools' strengths and weaknesses are presented in Table 3 below, and are included in individual toolbox entries.

*Table 4: MEDIATION tool strengths and weaknesess*

| Tool | Strengths | Weaknesses |
|---|---|---|
| **MCA- ANALYTICAL HIERARCHICAL PROCESSING (AHP)** | • Can be applied to complex problems where decision elements are difficult to quantify or not directly comparable<br>• Relatively simple approach to apply and gives easily understandable ranking that | • Results change as new options/ alternatives are considered in the analysis<br>• Some criteria are not independent so this can bias or complicate the way in which they are assessed (clusters can be formed) |

| | | |
|---|---|---|
| | are easy to communicate<br>• Flexibility – in terms of simple ranking of measures<br>• Does not require information on economic benefits and monetary valuation, and so it applicable to issues that difficult to value (e.g. ecosystems) or contentious<br>• Can accommodate a wide range of disciplines and opinions and groups of people who do not normally interact<br>• Allows integration of knowledge from different groups and an identification of conflictive items that could be clarified in the decision-making process (Parra-López et al., 2008:821)<br>• Offers a simplified way for making complex decisions, using simple mathematics (Parra-López et al., 2008:822)<br>• Enables the inclusion of multiple criteria, stakeholders and other decision-makers, in uncertain and high risk scenarios, where quantification of qualitative, subjective and intangible information is considered (Parra-López et al., 2008:822) | • Subjective scale can lead to biases and it is subject to human error (though inconsistency index can be calculated)<br>• AHP can become complicated if lots of criteria and options are considered<br>• Transdisciplinary capacity building considered critical in some contexts can be undermined at the cost of expediency the method provides<br>• Use of software can conceal conflicting value judgments, though inconsistency measures can be obtained. This can be avoided using a participatory approach as far as possible, before applying software analysis<br>• Subjective nature of modelling process: AHP cannot provide "universal" or "correct" decisions (Mesa et al. 2008)<br>• Is subject to rank reversal: as the sum of the local priorities to unity changes with the introduction of a new alternative, the local priorities are also modified when normalised and therefore the global priorities may be reversed (Ishizaka and Labib, 2011:14340) |
| **Economic Optimization Model** | • Based on neoclassical theory<br>• Widely used to reproduce farmers' behaviour and to calculate the impacts of given scenarios<br>• Powerful solver (GAMS) | • Permanent crops are assumed to already be in full production<br>• Farmers are presumed to be financially solvent<br>• Can suffer from aggregation bias when employing regional-level data |
| **AQUACROP** | • Good balance between robustness and output accuracy<br>• Developed and supported by FAO; fast growing network of users worldwide<br>• No specific training for use of the tool is required; enables non-specialists to develop scenarios<br>• Requires a relatively small number of explicit and mostly intuitive parameters and input variables<br>• Ideally suited for evaluation of climate change impacts; simulates $CO_2$ effects and permits differentiation between crops with different sink capacities | • Not yet available for fruit trees<br>• Not recommendable under saline conditions<br>• Can overestimate the $CO_2$ fertilization effect on crops<br>• Further improvements of the model for soil nutrition depletion, pests, diseases, and frost are possible |
| **WEAP** | • Very user friendly<br>• GIS-based interface enabling easy visualization of system components and simulation results<br>• Integrated approach; useful for developing integrated water resources planning assessments<br>• Model integration: dynamic links to other models and software, such as QUAL2K, MODFLOW, MODPATH, PEST, Excel, and GAMS | • Very data-demanding application<br>• Time scale: while natural processes occur on a daily basis, WEAP usually calculates water balance on a monthly time step<br>• All crops share the same water priority which means that shortages are equally shared amongst crops. This is not very realistic in some Mediterranean areas where in times of shortage, perennial crops are satisfied before annual crops. |
| **Socio-institutional network** | • Can provide measures | • Large sample size needed, or ego-centric |

| | | |
|---|---|---|
| **mapping (Quantitative approaches)** | • A range of software is available for visualization and analysis e.g. GEPHI, UCInet, ORA | partial networks<br>• Tends to focus on methodology and technical issues rather than on hypotheses and theories<br>• Over-interpretation of results<br>• Some authors have questioned an assumed confidence in the measures to characterize the networks<br>• Data are often difficult and expensive to obtain, and empirical studies are often quite small. This means it is hard to use data for exploration of alternative measurement strategies. |
| **Socio-institutional network mapping (Qualitative approaches)** | • Can be done in a day<br>• Encourages participation across diverse viewpoints and actors<br>• Does not prescribe a particular classification of jargon<br>• Yields insights that would be difficult to get any other way<br>• Range of software available for visualization and analysis e.g. Netdraw, UCInet, ORA, but can also remain hand drawn maps | • Can be difficult to integrate different perspectives to produce cohesive maps of whole networks, especially where multiple scales are involved<br>• Some links are less reliably attributed - information is incomplete<br>• Can be difficult to bring together actors that have different perspectives; this can cause tensions, which in turn can bias the results<br>• Results are highly dependent on which actors are involved in the exercise and which actors are not (high subjectivity). Therefore, it is important to ensure actor type representativeness when implementing SNM.<br>• One full day can be too long for some actors to participate. Poor participation of key actors can bias the results. |
| **Socio-institutional network mapping (both approaches)** | • Can generate an understanding of prevailing socio-institutional structures (based on how the actors themselves report them), relating a characterization of the individual actors connectivity, to its local network context, and to the overall whole-network features | • Subjective bias and can be difficult to generalize<br>• Time-consuming, intensive process<br>• Do not have a temporal or spatial dimension<br>• Networks have artificial boundaries (often necessarily)<br>• Design of process is critical to get as many differing viewpoints as possible |
| **Community Land Model** | • Mechanistic description of the fire process<br>• Ability to catch complex interactions between biophysical processes and fires<br>• Description of the anthropogenic impacts on spatio-temporal fire patterns | • High computational complexity<br>• Long computational time |
| **Simplified Standalone Fire Model** | • High flexibility for testing adaptation options<br>• Low computational complexity<br>• Adaptation options included in the modeling framework | • Less precise description of the interactions between fuel availability and fires |
| **Coupled VIC-RBM model** | • Process-oriented approach<br>• possibility to produce transient data | • large spatial resolution and lack of spatial detail<br>• no projections of point source evolution<br>• models are developed to simulate high discharge events and are not well adapted to low flows |
| **VIC and HBV Rhine model** | • the combination of two different model suits(one process based, the other | • using chains of scenario, GCM/RCM, hydrological models introduces a cascade of |

| | | |
|---|---|---|
| | empirical) allows for analysis of model uncertainties in outcomes | uncertainties. The quality of uncertainties and variations in model outcomes are difficult to assess.<br>• models are developed to simulate high discharge events and are not well adapted to low flows |
| **Semi-structured interviews applied to experts and policy makers** | • practical method to get expert opinions and state of the art knowledge | • risk of bias induced by interviewer, by selection of interviewed |

## 3.2 Improved variety of tools

The Guadiana case's study of stakeholder preference in terms of tools used highlighted that a single model (ex. Hydrological or crop model) is not always the best approach, and stakeholders prefer a broader collection of tools, including more participatory methods. Additionally, stakeholders seem willing to sacrifice to an extent the ability of a model to most accurately portray reality, and favor tools which improve the system's learning and facilitate the basin's management. These observations emphasize that the toolbox needed to not only focus on one chosen pathway of analysis, but should provide alternative options pathways in order to meet stakeholder needs.

Some concern was raised that the toolbox should improve access to more tools when possible, and integrate ease-of-use into the toolbox. While improving access is difficult, due to a number of reasons (including: tools not property of consortium members, no model with a user-interface or with relative ease of use, intellectual property pitfalls), the toolbox attempted to improve where possible. This was achieved via a 3 tiered system of access:

- 1st level: basic description of the tool, as per D 2.2 and improvements suggested here, with contact information of owners of the tool, plus a website or email address if possible. This category is for methods that may not be executable files, may be too complicated for average users, or require too much computing power for personal computers (models such as CLM, for example, falls into this category) The best we can hope to achieve is to provide a direct link to an external website that has a User's Manual for said tool, or, if no program exists, and the item in question is a method, than a link to a description of the method, plus contact information and relevant sources in articles.
- 2nd level: a direct link to the tool on an externally hosted website, accomplished via a hyperlink or button that links directly to a tool's web interface or download site. Certain tools (CLIMSAVE) are fully integrated into their web platform, others are available to download online, but require installation of files on the user's computer in order to run. Links are provided to User's Guides or Frequently Asked Questions, as well as contact information if possible. Access to external tools is a considerable improvement to the 1st level of access, as there is no installation required, however there would remain a lack of detailed information on use of the tool, and possibly less information on uncertainty and other parameters, as all information and material on the tool is from an external source.

- 3rd level: This represents the best access we were able to provide; applicable tools owned by consortium members have been incorporated into the common platform website wherever possible. Examples include IIASA's CATSIM tool, MCA Routeplanner from WUR, etc. The inclusion of these tools enable a user to download or run the selected model from the common platform, without navigating to external websites, bringing the tools and all their relevant information (tool use in the case studies, definition of relevant method types, descriptions of uncertainty, possible inclusion of instructions) together within the common platform.

While some interest was raised in linking tools together, due to the myriad complications involved with such an effort, along with the possibility of directly passing results from one model to another, it was decided not to follow this route, as the possibility of different assumptions used by each separate module could have the effect of increasing uncertainty, as the transparency of the entire process is reduced, and users could be unsure as to strengths and weaknesses of the individual tools

## 3.3 NOVEL MEANS OF CONVEYING INFORMATION

Since its inception, the toolbox has had to balance between increasing content and improving upon the content already incorporated; any platform is essentially useless, no matter how unique and potentially informative the framework may be, if there is no content, however, simply creating a massive index of all tools applicable to IVA analyses would also be uninspiring if not for effective and novel ways of improving user application of such tools.

While the UNFCCC Compendium of Methods was chosen as a template for the MEDIATION toolbox, it has been found to have limited applicability in the project. The database structure of the Compendium is too limited for the toolbox contents, as our methods may not always be adequately described. While the Compendium is well organized and documented in relation to individual methods, it lacks an overarching typology for organizing and sorting tools. Research throughout MEDIATION has shown that there are multiple entry points to CCIAV analysis, and that there is a vast number of applicable methods and tools which exist. Together with work package 4, we have tried to create our own typology which makes sense of the multitude of approaches and methods, and which we feel improves upon the UNFCCC Compendium of Methods. The improved typology is discussed in further depth in Chapter 5, and we feel it improves upon the stated goals of the Compendium to "assist Parties and other potential users in selecting the most appropriate methodology for assessments of impacts and vulnerability, and preparing for adaptation to climate change (UNFCCC, 2013)". By creating a logical framework within which to organize the multitude of approaches, methods, and models relevant to CCIAV, we more successfully assist users in navigating and selecting appropriate items for their assessments.

Beyond the change in overall organization, we chose – based on the deliverable 4.1 on uncertainty – to make individual tool descriptions less structured, incorporating all the items from the Compendium structure in a more free-flowing format, with five major categorical headings. They are:

- Description
- Applicability
- Strengths and weaknesses

- Access
- Previous research / References

D4.1 emphasizes parsimony, personalization, and practicality. The broad categorization defined above allows users of the toolbox to quickly have an overview of each item without overwhelming the reader with information, addressing parsimony. Strengths and weaknesses provide the reader with personalized experiences of researchers, as they have provided their own feedback on each tool after its use in a MEDIATION case study, corresponding to personalization. As the toolbox provides a user with information and linkages to other similar tools in the same or different sectors, or with alternative approaches to analysis, it helps to address the third pillar from D4.1, practicality.

Within these five categories, any applicable information, such as cost of access, ease of use, technical knowledge required, strengths and weaknesses, sectors used, etc., is addressed as needed. The UNFCCC Compendium allows for easy cataloging of toolbox items on the common platform, and its structure was maintained for database use, but display of tool descriptions in the final toolbox reflects the above 4 categories. This allowed for incorporation of datasets, other information platforms, methods without computer executables, and other miscellaneous tools included in the toolbox that were not adequately addressed by the framework of the UNFCCC.

Most of the relevant improvements to access and conveying of information has not been separate from work done in other work packages. WP 2 has worked closely with WP 5 (developers of the common platform) in order to implement the changes and designs that we propose here. The toolbox, common platform, and integrated methodology are very interlinked; every tool in the toolbox corresponds to a method type as described in D4.2, and will allow for close linkages to the resulting integrated methodology. The common platform prototype already has very seamless integration between descriptions of cases, methods, and the toolbox, which has been improved upon by the typology in Chapter 5.

# 4 AN IMPROVED TYPOLOGY OF METHODS AND MODELS

Along with changes to the toolbox at an individual entry level, restructuring of the toolbox took place at a higher, typological level. As the word "toolbox" is used in many scientific disciplines with varied meaning, we feel it is necessary to clarify that the objective of the MEDIATION toolbox is: to create a package of items that can be utilized in some way by a user when thinking about climate change adaptation. That usage is broad in scope, from incorporating relevant climatic or other data sets into an adaptation decision-making process, to implementation / use of methods such as MCA, CBA, etc., or use of more complex models requiring a computer or perhaps shared computing resources (i.e. larger models like CLM). We feel this definition suits the needs of the MEDIATION DoW as well as provide a valuable input to the common platform, integrated methodology, and the toolbox's potential users, while working within the limits of what can practically be accomplished within the scope of the project.

The inclusion of broader methods (such as cost benefit analysis) as well as specific models such as CATSIM necessitated a way to distinguish between the two types of entry. Additionally, as work package

4 progressed on a typology of methods and the final integrated methodology, a more structured approach to climate change adaptation analysis came forward, as well as a typology of methods which lent itself very well to an organizational structure for the toolbox. In collaboration with work package 4, we adapted a new typology, which organized CCIAV methods and tools from a broad view, beginning with sorting by types of approaches (e.g. Participation and engagement or Impact analysis), with a given subgrouping of methods, each possibly pertaining to tools in the toolbox. In this way, a hierarchical tree was developed which allowed for MEDIATION tools to be sorted in a manner consistent with the main output of the product and component of the common platform. It also allowed for specific entries on both models and methods, as there exists a clear distinction between the two. An example extracted from the resulting typology of methods and models is provided in table 3 below. The entire typology is too large to reproduce here, but is provided in Appendix II and is accessible online.

The new typology allows for a hierarchical tree structure which can be subdivided as many times as is necessary. From the broadest category of types of approaches, rough distinctions can be made, e.g. impact analysis can be divided into two categories: describing current impacts and modelling future impacts. As there are a vast amount of methods and tools related to future impacts, we can further subdivide the category into model-based projections, vulnerability indications, and participatory methods of vulnerability assessment. Model based projections consist of biophysical and socio-economic models; as there are a wealth of biophysical models relating to various sectors, we further subdivide the categories in this way, creating a tree-like structure.

*Table 5. An example of the typology of methods and models*

| **Type of approaches** | **Method (level 1)** | **Method (level 2)** | **Method (level 3)** | **Method (level 4)** | **Tools** |
|---|---|---|---|---|---|
| Impact analysis | | | | | |
| | Modeling future impacts | | | | |
| | | Participatory methods of vulnerability assessment | | | |
| | | | Community vulnerability assessment | | |
| | | | | Capacities and vulnerability analysis (CVA) | |
| | | | | Vulnerability and Capacity Assessment (VCA) | Socio-inst. Network mapping |
| | | | | | CRiSTAL (Community Based Risk Screening) |
| | | | Expert judgment | | |

| | | | | | |
|---|---|---|---|---|---|
| | | | Participatory scenario development | | |
| Capacity Analysis | | | | | |
| | Indicators of adaptive capacity | | | | |
| | Participatory Vulnerability and capacity assessments | | | | |
| | | | | | |

The improved typology extends beyond the initial categorization of D2.2 by distancing itself from past efforts and literature which broadly divided tools into Impacts, Vulnerability, Adaptation, and Integrated Assessment Tools. The top level of categorization (types of approaches) allows for the following categories: participation and engagement, impact analysis, capacity analysis, behavioural analysis, institutional analysis, decisionmaking, planning and implementation, monitoring and evaluation, learning and reflection, valuation, scenario analysis, and treatment of uncertainty.

Another improvement resulting from the new typology is the combination of information on both methods and tools. Users can quickly navigate to a desired agricultural model, or read about biophysical models more generally, or even stepping back further to a broader discussion of model-based projections.

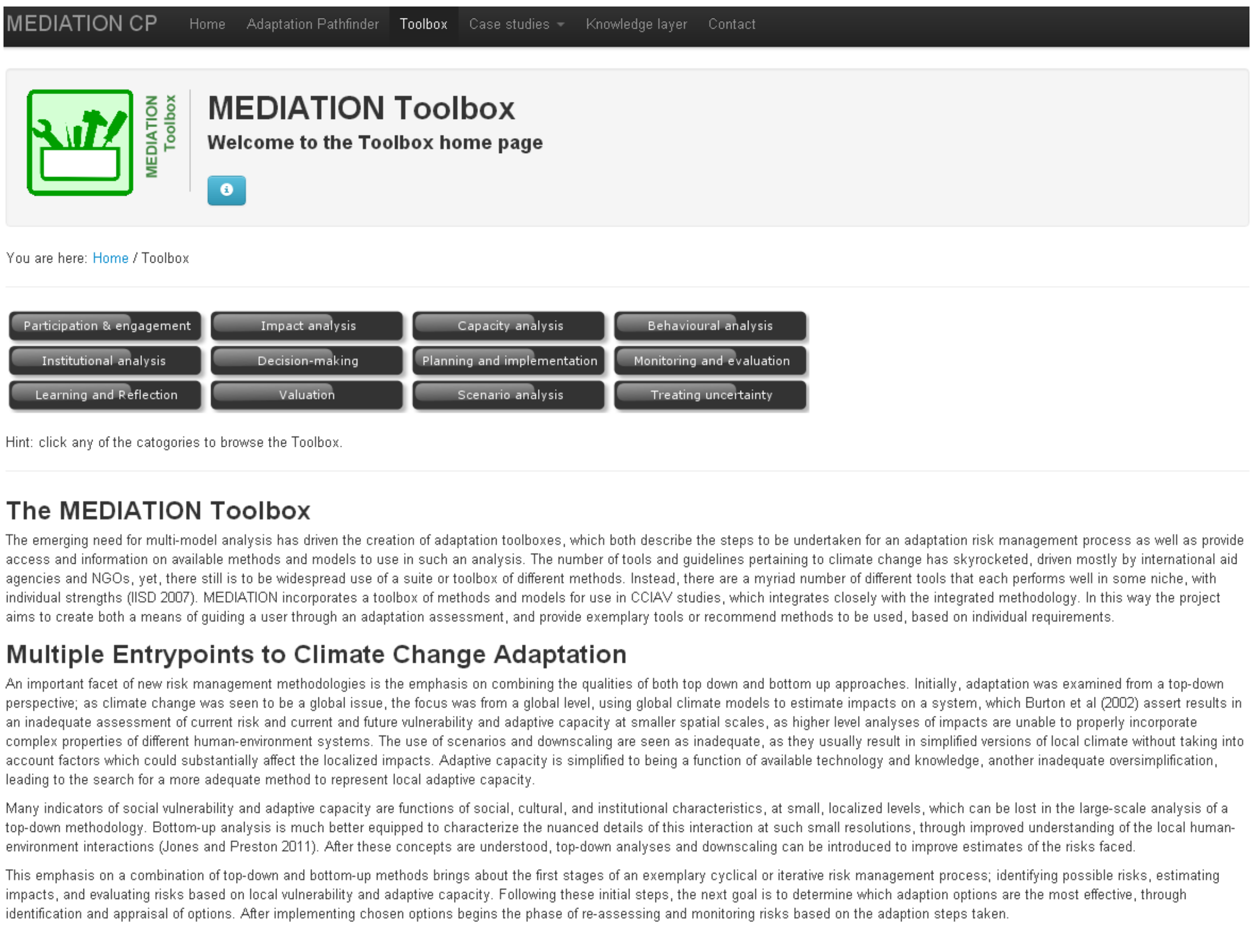
# 5 THE FINAL MEDIATION TOOLBOX

The changes and improvements outlines in Chapters 4 and 5 were implemented into a final toolbox iteration, which is now referred to as the MEDIATION Toolbox of Methods and Models, incorporating feedback from case study-stakeholder interactions, improved methods and metrics from individual cases, as well as improved linking of tools and methods with other portions of the Common Platform, notably the final diagnostic framework for problem-oriented climate change adaptation research.

With a final framework and tool description in place, the toolbox was filled with a selection of methods and models derived from all of the MEDIATION case studies. These tools are the mainstay of the toolbox, and contain input from case study members who utilized the tools extensively and provided information on strengths and weaknesses in an attempt to help reduce uncertainty. Beyond MEDIATION tools, and in line with D2.2 where we outlined a goal of gap-filling in order to provide more coverage in regards to missing tools, selected models and methods have been added to provide a more complete representation of the types of tools needed to carry out all stages of an adaptation assessment (for example, tools and methods relating to trend detection and statistical downscaling have been added, as they are important initial steps in CCIAV analysis, yet were not as heavily represented in final case study papers). Also, where possible, tools were added covering sectors not discussed in MEDIATION, such as coastal zone and multi-sector models not used in MEDIATION. All tools added to the toolbox have been included in Appendix III of this deliverable.

While initially seen as separate work streams, socio-economic evaluation methods from Work Package 3 were also incorporated into the toolbox, as the new typology allowed for the toolbox to represent all stages of CCIAV analysis, thereby consolidating all relevant information into one location, reducing complexity for end-users.

The resulting product of Work Package 2 and outlined above is a web-based toolbox of methods and models, closely linked to the integrated methodology and case study navigator on the Common Platform website. A screenshot of the toolbox can be seen in Figure 1 below.




As seen above, the typology allows for quickly finding information on a relevant tool or method based on the framework of the integrated methodology. Each level of method has a corresponding description, providing the user with as much or as little background information as is desired. Clicking on a tool brings the user to an individual tool description, shown below in Figure 2.

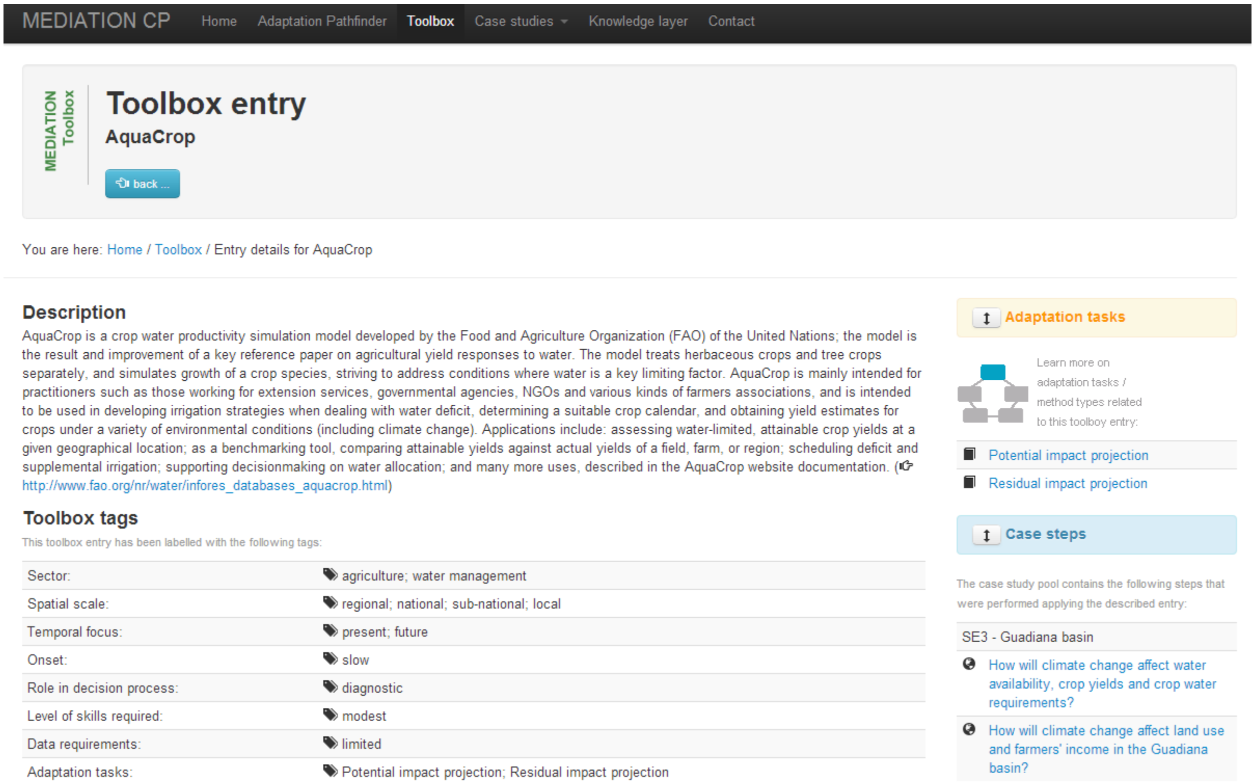


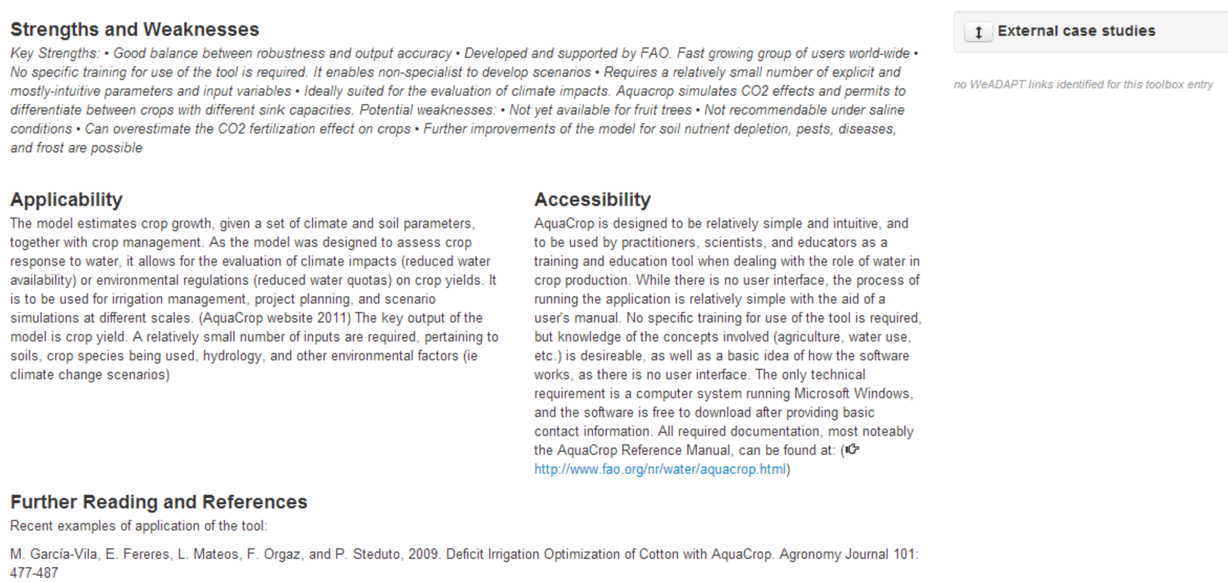

*Figure 3. First half of an example tool entry page from the MEDIATION toolbox*

As seen above, individual tool descriptions begin with a short paragraph describing the tool. Underneath this description is a section for toolbox tags, a set of useful descriptors initially designed to use as sorting criteria, but also with descriptive value. They are:

- Sector: What sectors the tool is applicable to (the toolbox uses similar sectors as the IPCC)
- Spatial scale: An approximate assessment of what spatial levels the tool is used for. Scale is defined as either local, sub-national, national, regional, or global
- Temporal focus: Indicates if tools are used primarily for present-day estimates, or if they have applicability to future projections
- Onset: This tag differentiates between slow- (e.g. sea level rise) and sudden- (e.g. riverine flooding) onset events, if applicable
- Role in the decision process: Assesses whether a tool functions in a diagnostic or prescriptive fashion
- Level of skills required: Roughly indicates the level of background knowledge a potential user would need; limited skills would indicate that relatively any user interested could real applicable user's guides and have a measure of success with the tool. Modest skills would require more in-depth knowledge and experience, (e.g. some level of computer or programming language experience, or a statistics background). A High level of skills required indicates that it is highly unlikely that an average user, unfamiliar with the tool, would ever be able to successfully use it. Certain tools require an extremely high amount of knowledge and computing power, with entire servers dedicated to their use, which would be a limiting factor for most users.

- Data requirements: Similar to level of skills listed above, this indicator provides a rough idea to the user what they could expect in terms of inputs needed. Limited data requirements indicates very little specific data is necessary; modest may require a number of input parameters or small datasets, and high data requirements would indicate the need for large, complex, and possibly expensive datasets, usually spatially explicit and not easily obtainable to an average user not familiar with the tool or data.
- Adaptation tasks: This tag links the tool to the Adaptation Task Navigator, and lists where the tool could be applied within the methodology.

On the right hand side of the screen, links to the relevant adaptation tasks are provided, as well as to specific case study steps where the tool may be used, providing users with added context and an ability to see application of the tool within the project.


**Strengths and Weaknesses**

*Key Strengths: • Good balance between robustness and output accuracy • Developed and supported by FAO. Fast growing group of users world-wide • No specific training for use of the tool is required. It enables non-specialist to develop scenarios • Requires a relatively small number of explicit and mostly-intuitive parameters and input variables • Ideally suited for the evaluation of climate impacts. Aquacrop simulates CO2 effects and permits to differentiate between crops with different sink capacities. Potential weaknesses: • Not yet available for fruit trees • Not recommendable under saline conditions • Can overestimate the CO2 fertilization effect on crops • Further improvements of the model for soil nutrient depletion, pests, diseases, and frost are possible*

**Applicability**

The model estimates crop growth, given a set of climate and soil parameters, together with crop management. As the model was designed to assess crop response to water, it allows for the evaluation of climate impacts (reduced water availability) or environmental regulations (reduced water quotas) on crop yields. It is to be used for irrigation management, project planning, and scenario simulations at different scales. (AquaCrop website 2011) The key output of the model is crop yield. A relatively small number of inputs are required, pertaining to soils, crop species being used, hydrology, and other environmental factors (ie climate change scenarios)

**Accessibility**

AquaCrop is designed to be relatively simple and intuitive, and to be used by practitioners, scientists, and educators as a training and education tool when dealing with the role of water in crop production. While there is no user interface, the process of running the application is relatively simple with the aid of a user's manual. No specific training for use of the tool is required, but knowledge of the concepts involved (agriculture, water use, etc.) is desireable, as well as a basic idea of how the software works, as there is no user interface. The only technical requirement is a computer system running Microsoft Windows, and the software is free to download after providing basic contact information. All required documentation, most noteably the AquaCrop Reference Manual, can be found at: (http://www.fao.org/nr/water/aquacrop.html)

**Further Reading and References**

Recent examples of application of the tool:

M. García-Vila, E. Fereres, L. Mateos, F. Orgaz, and P. Steduto, 2009. Deficit Irrigation Optimization of Cotton with AquaCrop. Agronomy Journal 101: 477-487

**External case studies**

*no WeADAPT links identified for this toolbox entry*

*Figure 4. Second half of an example tool entry page from the MEDIATION toolbox*

Figure 2 above displays the second half of a typical MEDIATION tool entry. Strengths and weaknesses are provided by case studies where possible to assist users in understanding the benefits and limitations of tools and methods. Applicability describes potential uses of the tool, and provides links or examples of past work. Accessibility elaborates upon the tags listed above and describes particular details about tool use and access, as well as where to find any user's guides or information.

# 6 Conclusions and a way forward: Iterative Risk Management

The concept of analysing climate change impacts by linking together independent parts into an integrated risk assessment is not a recent development; Shlyakhter et al (1995) discuss the possibility of utilizing integrated risk assessments to analyse global climate change. Emphasis on probabilistic risk estimates is also relatively well discussed. Pittcock et al (2001), in a letter to *Nature*, emphasize a greater use of probability in climate change decision-making and Jones (2001) defines a 7 step probabilistic risk management framework for climate change impacts. While implementation of a risk-based process that emerges does not directly improve estimates of impacts, vulnerability, adaptive capacity, or the related uncertainties, but Shlyakhter et al (1995) argue that clearly defining a process is a necessary step that improves quality of the overall assessments. They also acknowledge that such a process may not perfectly describe or predict a system, but the act of following the framework supplies benefits on its own, such as ensuring that no important processes are left out of the analysis.

While the traditional approaches to risk management are increasingly applied to adaptation problems, there still exists a lack of implementation and monitoring, which has recently been addressed by the concept of iterative risk management, described most recently in in Jones and Preston (2011) and put into action by guidance documents such as the UK Climate Impacts Programme, Natural Resources Canada's Tools for Adaptation, among others. An iterative risk management approach, described in **Error! Reference source not found.** combines an initial step of risk identification with subsequent analysis (What are the risks of climate change?), evaluation (How could we adapt to change?), management (What are the most effective adaptation options?), and implementation of projects. Jones and Preston assert the need to subsequently investigate the results of that implementation in a monitoring step, creating a cyclical process, with the final evaluation of adaptation measures resulting in a new step of risk identification, which then restarts the risk assessment cycle.

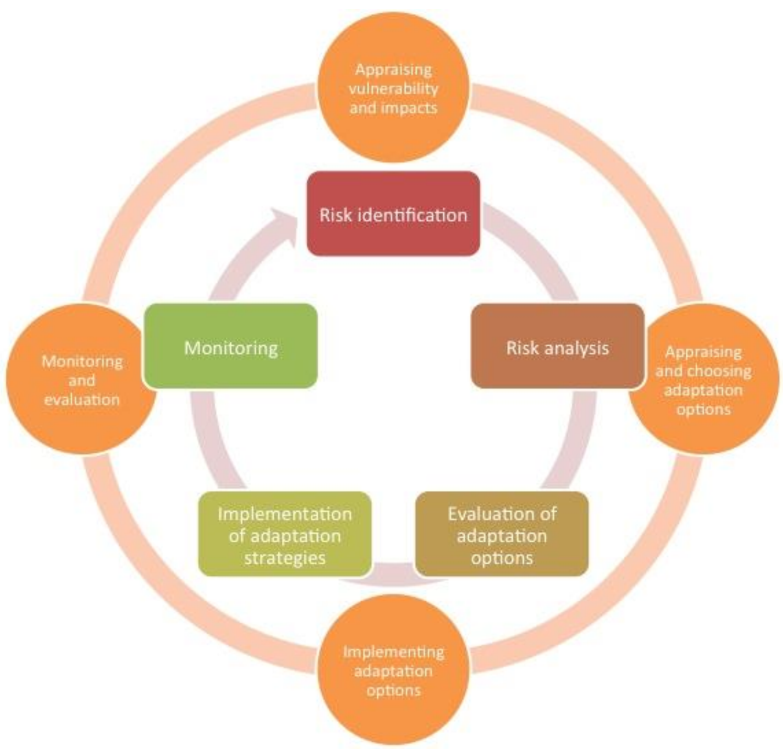



*Figure 5. An example of the cyclical basis of an iterative risk management approach (modified based on SREX 2011)*

The process described above, while specifically consisting of risk identification, analysis, evaluation, etc., can be considered to be more broadly anchored by four overarching themes that the iterative risk management process undertakes: monitoring and evaluation, awareness, learning, and innovation. These themes are loosely correlated as seen above, but as discussed below, there are areas of overlap.

1. *Monitoring and evaluation- defining the system to be studied, and estimating future biophysical trends and impacts.*

   Recent work has shown that improved monitoring merits emphasis. Lorenzoni et al (2005) show a need for enhanced monitoring as well as communication with stakeholders at all stages of an assessment. This stage of assessment incorporates detection of climate trends and highlighting possible future climactic impacts, as well as monitoring and evaluating relevant socio-economic and institutional factors, such as climate and adaptation-relevant policymaking..

2. *Perception and governance- Evaluating other factors of the system under study, namely, socio-economic and policy / institutional factors*

   Climate hazards have been shown to be linked to and interact with "psychological, social, cultural, and institutional factors, resulting in amplification or attenuation of individual and social representations of risk and danger" (Lorenzoni 2005). This implies that an accurate understanding of the social and institutional processes is required in order to best model the effects of an impact as well as effectively implement adaptation strategies and monitor their progress. Perception is concerned with identifying and understanding actors, policies, climate impacts and vulnerabilities, from both a top-down and bottom-up perspective. As highlighted by Burton et. al. the use of global climate models exclusively to forecast future risks is inadequate to accurately represent risks.

3. *Learning- Assessing vulnerability, and assessing available adaptation strategies*

   This emphasizes what can be considered the most vital stages of an assessment; processing of information on risks and determining the most applicable adaptation strategy.

4. *Innovation- the transformation of society toward sustainability and resilience*

   This movement reflects both social, non-material changes or technological ones (e.g. dike construction) The term is loosely defined in order to reflect the vast possible types of innovations which may be possible in the future, but broadly describes any step taken to move towards a more resilient future.

While the terms may be delineated in the above graphic and descriptions, there are as mentioned large areas of overlap, and the cycle can be seen as more gradual or fluid, unlike the relative rigidity of the iterative risk management cycle.

## 6.1 Perception and fusing top-down and bottom-up approaches

An important facet of new risk management methodologies is the emphasis on combining the qualities of both top down and bottom up approaches. Initially, adaptation was examined from a top-down perspective; as climate change was seen to be a global issue, the focus was from a global level, using global climate models to estimate impacts on a system, which Burton et al (2002) assert results in an inadequate assessment of current risk and current and future vulnerability and adaptive capacity at smaller spatial scales, as higher level analyses of impacts are unable to properly incorporate complex properties of different human-environment systems.  The use of scenarios and downscaling are seen as inadequate, as they usually result in simplified versions of local climate without taking into account factors which could substantially affect the localized impacts. van Aalst et al (2008) highlight the example of crop yields, which are sensitive to a number of microclimatic effects, such as temperature variability, seasonality, rainfall distribution, and others.

Burton and van Aalst also assert that the use of a classical top-down approach is flawed due to the focus on future climate, assuming that impacts will be "reduced by the process of adaptation under unknown future socio-economic circumstances" (van Aalst, 2008). Adaptive capacity is simplified to being a function of available technology and knowledge, which is seen as an inadequate oversimplification, leading to the search for a more adequate method to represent local adaptive capacity.

Many indicators of social vulnerability and adaptive capacity are functions of social, cultural, and institutional characteristics, at small, localized levels, which can be lost in the large-scale analysis of a top-down methodology. Bottom-up analysis is much better equipped to characterize the nuanced details of this interaction at such small resolutions, through improved understanding of the local human-environment interactions (Jones and Preston 2011). After these concepts are understood, top-down analyses and downscaling can be introduced to improve estimates of the risks faced.

This emphasis on a combination of top-down and bottom-up methods brings about the first stages of an exemplary cyclical or iterative risk management process; identifying possible risks, estimating impacts, and evaluating risks based on local vulnerability and adaptive capacity. Following these initial steps, the next goal is to determine which adaption options are the most effective, through identification and appraisal of options. After implementing chosen options begins the phase of re-assessing and monitoring risks based on the adaption steps taken.

## 6.2 Adaptation and Learning

As estimates of climate change impacts have evolved from 30+ years ago until today, the focus of estimates have obviously enough changed as well, as initial methods are improved and accepted, and arriving to the currently proposed framework. A large portion of this methodology, which was recently emphasized in the Special Report on extremes, is the growing need and use of learning oriented methods. While a comprehensive overview of the influence and relation of learning oriented methods to adaptation is beyond the scope of this research, the growing emphasis on learning necessitates its inclusion here in summary as well as in the overarching approach to future adaptation analysis.

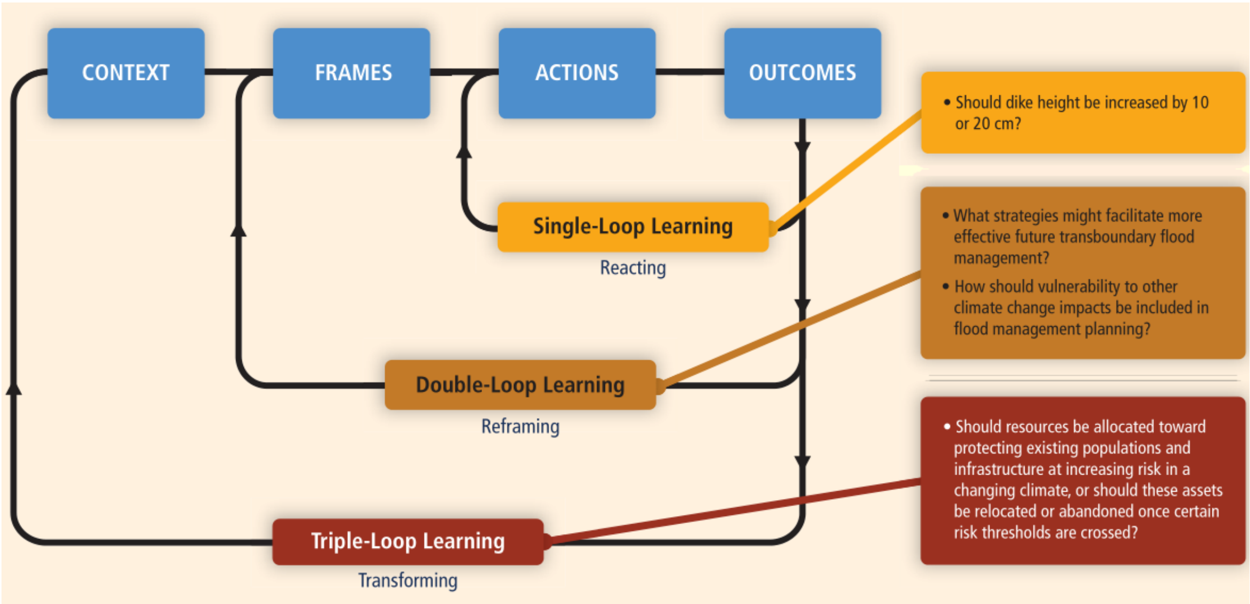



*Figure 6. Learning loop framework, source: IPCC 2012*

**Error! Reference source not found.** presents a synthesis of the myriad of literature developed in relation to adaptation learning, and illustrates the different approaches proposed, as well as the complexity which surrounds the idea of learning and adapting over time while also coping with extreme stresses and functioning normally as a system. *Single loop learning*, the simplest loop possible, is an analysis of if an action being performed is sufficient. An example would be observing drought insurance measures and determining if they are adequate to mitigate damages. One step removed from that is *double loop learning*, or reframing the issue and asking if there are any other approaches which could also be taken to, in this case, adapt to increasing drought risk. The broadest perspective, one of transformation via *triple loop learning*, puts climate change impacts into context with other global issues. Our example would then lead to the question of possibly determining a level of resilience and risk which are acceptable, in order to focus resources on other development goals such as growth and/or poverty issues.

The differing types of learning are not prioritized, and each type has its own strengths and weaknesses. Single loop learning is efficient and focused, but leaves out the larger perspective. Triple loop learning, on the other hand, incorporates climate risk into a larger worldview, and can lead to larger transformations in a system (Pelling, 2010), but is difficult due to the sheer scale of such an undertaking, and the associated difficulties such as improving collaboration between stakeholders, and defining a single idea of what the goals of the system should be.

## 6.3 Conclusions

Over the past 42 months, Work Package 2 of MEDIATION has worked to develop improved methods and metrics relevant to climate change impacts, vulnerability, and adaptation, and to collect the work into a framework typology now known as the Toolbox of Methods and Models. Initial work for D2.1 provided an overview of CCIAV methods, and started working towards an improved typology. D2.2, on the basis of D2.1, outlined a framework for an iteratively designed toolbox and provided a blueprint for the way forward throughout the project, and put forth the toolbox as the main product of the work package and the best way to achieve and communicate the stated goals of increasing integration between methods, improving methods and metrics, and reducing uncertainty.

Since drafting D2.2, the case studies and toolbox have undergone a number of iterations, and produced a variety of results contributing to the work package goals. Cases highlighted novel ways to communicate uncertainty via improved descriptions of tools as well as their strengths and weaknesses, improved metrics were proposed which provide policy-relevant and useful information to stakeholders and policymakers, and methods were improved upon and new tools created to fill gaps in previously existing research.

The resulting product is a toolbox which links methods, models, and approaches in such a way that highlights the complex nature of CCIAV analysis, emphasizing the existence of multiple entry points to assessment, based on the approach used. While most "toolboxes" can be viewed as being closer to catalogues or lists (D2.2, 2010), the MEDIATION toolbox adds value due to a logical and novel framing, which improves upon the previous long lists of tools. Users can now find tools not just by sector or relevant method, but can see at a glance how these tools and methods fit into an iterative approach to CCIAV analysis. It also adds a new understanding and appreciation for the number of tools and methods which currently exist. The all-encompassing approach of the toolbox allowing for different entry points emphasizes just how many methods current exist, and all the ways in which they can be used. The typology of methods and models brings coherence to a field which currently lacks it, which we feel is an extremely important result, and could contribute to recognizing a coherent interdisciplinary framework.

The toolbox also highlights just how vast the amount of possible future work could be. By fitting tools and methods into our typology, we've highlighted large imbalances even while emphasizing the multiple entry points to analysis. Certain areas have an overabundance of tools, notably from the natural sciences, whereas there is a lack of tools from the social science realm. The typology highlights that while Institutional analysis and governance is an important approach, there are few methods and tools developed in that area, necessitating further research and development of new tools. Other follow-up work for the toolbox and typology could include further testing in Europe and improvement of the current contents, as well as linking to European testing of the Provia research on climate change vulnerability, impacts, and adaptation. We have also made the contents of the toolbox available for inclusion into the EEA's recent web platform, CLIMATE ADAPT, in order to supplement their growing database of models.

Finally, we present a way forward for future CCIAV research in the form on greater emphasis on the cyclical process of Iterative Risk Management frameworks, which shares similarities to the integrated methodology developed by WP5. Emphasizing learning at multiple levels, combined with fusing top-down and bottom up approaches, in an adaptive management framework can serve as a valuable methodology to approach climate change adaptation and constitute a framework within which to utilize CCIAV methods and metrics in the future.

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# APPENDIX I: CASE STUDY REPORTS

## THE EUROPEAN FOREST FIRE CASE

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Adaptation to climate change becomes increasingly important for the scientific community and also for decision makers as the impacts already observed in the past are expected to become even stronger in the near future (Pechony and Shindell 2010; Rego et al. 2010a; San-Miguel-Ayanz et al. 2012b; Schelhaas et al. 2010). Even though numerous other papers present topic- and region- specific case studies, some of them still lack a clear and systematic description of the methods and assumptions being used, which makes interpretation and comparison of the results difficult. This analysis, focusing on assessment of impacts of reactive and preventive adaptation strategies to forest fires in Europe, is a pioneering attempt to overcome these limitations by providing a quantitative analysis within one modelling framework, and applying a common approach for each step of the research process, consistent with other case studies in the EU FP7 MEDIATION project (Hinkel et al. in preparation).

Fires are widely recognized as one of the main disturbances affecting terrestrial ecosystems, with a profound impact on global climate, air quality (through emissions of greenhouse gases, black carbon, aerosols and their precursors), surface albedo, and vegetation structure and functioning (Bowman et al. 2009; Marlier et al. 2012). In Europe, fires are one of the main disturbances affecting carbon sequestration of forests and also leading to loss of life (e.g. (Lindner et al. 2010)). At the same time, especially in Mediterranean ecosystems fire plays an important role in life cycle of many plant species (Venevsky et al. 2002) and therefore maintains biodiversity. The link between forestry and climate change is twofold: forests act as sinks for carbon dioxide, yet at the same time they are very vulnerable to changes in weather conditions that can reduce the carbon sequestration potential, and increase the probability of disturbances, such as fires.

Fire regimes are determined by climate, vegetation and direct human influences. Climate is recognized as the major determinant of fire patterns at global scale (Marlon et al. 2008), in particular when climatic conditions are severe (Archibald et al. 2009). In Europe and in Mediterranean basin it is generally recognized that the occurrence of fires is mainly determined by causes of an anthropogenic nature (Z. Naveh and J.-L. Vernet 1991), although year to year burned areas are linked to weather conditions (Rego et al. 2010a).

The projected decrease in summer precipitation in southern Europe and the increase in the frequency of summer droughts will probably induce greater risks of forest fires (Alcamo et al. 2007). Active forest and fire management practices can counteract the impacts of a changing climate to some extent. Currently, there is little work on modelling of the impact of adaption options on reducing fire occurrence probability and burned area.

An analysis of the risk management and adaptation options to fires in European forestry at national level shows that an increase in harvest level can stop the current build-up of growing stock and possibly decrease the vulnerability through the reduction of old and vulnerable stands (Schelhaas et al. 2010). Changing species from conifers to broadleaves might be also a viable option in a long run (Schelhaas et al. 2010). Other analyses show that the creation of agricultural fields in marginal areas is one of the most promising strategies to mitigate the effects of climate change on fire regimes, as agricultural fields can act as fire breaks preventing the spread of fire and hence reducing burned area (Lloret et al. 2002; Loepfe et al. 2012). Nevertheless, no realistic management strategy is able to totally offset the effect of climate change (Loepfe et al. 2012). In Mediterranean areas prescribed burnings are found to be one of the most promising adaptation strategies lowering the fuel load and reducing fires spread ultimately leading to consistent reductions of large fire events (Loepfe et al. 2010). Another option highlighted in literature is the enhancement of fire fighting capacities supporting reduction of the total burned area (Piñol et al. 2007).

The present study is designed to explore the impact of adaptation options to forest fires in Europe according to the “diagnostic framework for problem-oriented adaptation research" (Hinkel et al. in preparation), which defines five broad iterative tasks in the adaptation learning cycle: i) appraising climate change vulnerability and impacts, ii) identifying adaptation options, iii) appraising adaptation and choosing adaptation options, iv) implementing adaptation actions, and v) monitoring and evaluating adaptation action and learning. An important aspect of this framework is the stakeholder interactions, which was also an essential component of this forest fire research.

This work is focused only on the initial stages (appraising climate change impacts and identifying and appraising – the effectiveness of - adaptation options) of the adaptation learning cycle and not on the implementation, monitoring and evaluation of adaptation action and learning. The main aims of our study are:

1) to quantify the potential impacts of climate change on burned area in Europe,
2) to quantify the potential effectiveness of different adaptation measures at pan-European scale.

Among the different adaptation options we test fuel removal via prescribed burnings and enhancement of fire suppression. In the following sections, we formulate the sequence of questions and explain applied methods (section 2), the results obtained (section 3), and document new insights gained with the analysis (section 4).

**Applied methods**

**Overview**

In this section we provide a brief overview of the steps carried out in the course of our study. A schematic diagram of the methodology followed to address the questions regarding adaptation options to forest fires in Europe is presented in Figure 1. The diagram is intended to describe the adaptation learning cycle applied in this case study, which comprises of three broad iterative steps needed for 1) projecting potential impacts; 2) projecting residual impacts of adaptation options 3) appraising and choosing adaptation options. The latter step was carried out in consultations with forest fires expert and potential stakeholders during consultations organized for this purpose.

Step 1 focused on the assessment of potential impacts and consists of selecting, implementing, and refining of appropriate tools (i.e. models) to simulate the future potential impacts of climate change on fires occurrence and burned area at pan-European scale.

Step 2 focused on the choice of options and the assessment of the effectiveness of selected adaptation options to reduce burned area in Europe.

Step 3 focused on the discussion with sector experts and stakeholders on the results obtained in steps 1 and 2, with the main goal of sharing information about the estimated effectiveness of adaptation options, and sharing information useful for the development and improvement of our methodology. Steps 1, 2 and 3 utilize feedbacks to refine the predicted impacts, reduce uncertainty and share information.

**Selection of tools and assessment of impacts (step 1)**

In this step we addressed the problem of finding a suitable way of modelling the potential impact of climate change on forest fires probability and burned area in Europe. For this purpose we applied a widely used terrestrial biosphere model (Community Land Model, CLM) (Levis et al.; Stöckli et al. 2008) extended with a carbon-nitrogen biogeochemical model (Randerson et al. 2009; Thornton et al. 2009; Thornton et al. 2007). Most of the updates of the model are described in (Lawrence et al. 2011). The prognostic treatment of fires is based on the fire algorithm developed by (Arora and Boer 2005), modified and implemented within CLM by (Kloster et al. 2010), and further refined and parameterized for the application over Europe as in (Migliavacca et al. 2013) finally evolving to the CLM-AB model. CLM-AB was calibrated by using fires statistics reported in the European Fires Database (EFDB) developed in the context of the European Forest Fires Information System (EFFIS), (San-Miguel-Ayanz et al. 2012b). CLM-AB includes both climatic and socio-economic drivers of forest fires, therefore, it allows the implementation of adaptation strategies in the model code. This model was selected also because it is able to catch the complex interactions between burned area, climate, and fuel variability in Europe (Migliavacca et al. 2013). One drawback of CLM-AB is the high demand of computing resources that might hamper the testing of a full range of adaptation options. For this reason a simplified stand-alone version of the CLM-AB model (further referred to as SFM), which exploits the outputs of CLM-AB, was developed to test the impacts of different adaptation options. Below we describe the modelling framework used in the present study in more detail.

**Description of applied modelling strategies**

*Derivatives of the CLM-AB model*

One modelling approach used in this study is entirely based on the CLM-AB model further refined and parameterized for the application over Europe as in (Migliavacca et al. 2013). The main advantage of the modelling approach based on CLM-AB is its ability to catch complex interactions between biophysical processes and fires. However, a detailed interlinked modelling system implies processing of a rich set of variables at fine spatial and temporal resolutions. Consequently, this leads to a high computational complexity and high processing power demands, ultimately resulting in long computing times. To overcome these problems we developed the SFM model, which exists in two versions sharing the same source code. One version of SFM is in fact a CLM-AB's fire module decoupled from CLM-AB itself (further referred to as SFM-C), which aims at mimicking the CLM-AB's burned area output utilizing a subset of CLM-AB input and output variables (moisture, fuel biomass, and wind speed) that are external to the fire module itself. SFM-C provides faster computing time at the cost of losing the fire feedbacks to the biophysical part of the model. The other version further referred to as SFM-F is even more different from the CLM-AB. It is utilizing only datasets fully independent from CLM-AB (weather, biomass, population density) and does its own fuel moisture computation from the ground up, based on the Canadian fine fuel moisture code (FFMC) index (Van Wagner and Pickett 1985).

*Models' calibration*

An important factor influencing the fire situation in Europe is suppression; it depends on local regulations and available resources, which vary from one country to another. The original setting of the CLM fire module aimed at global application, as documented in (Kloster et al. 2010), assumed one global value representing the efficiency of fire suppression – defined as probability of putting out a fire on a given day. In the original model setup, this probability does not depend on fire duration, weather conditions and the total number of active fires in a region on a given day. This form of a simplified representation of the fire extinguishing probability implies rather a proxy of a suppression potential and is describing such key factors as ability to detect and put out fires, conditional on availability of respective resources. Potential area burned within one day (and also accumulated burned area over any time period) in both CLM-AB and SFM models can be represented as

$$A(q) = a\,(1-q)\,(2-q)/q^2, \tag{1}$$

where the coefficient $a$ does not depend on the aforementioned proxy variable denoted here as $q$. In the calibration procedure for a specific country and a time period we find such value $q_c$ of that proxy variable (further referred to as "calibrated") that provides that equality $A(q_c) = A_{obs}$ holds, where $A_{obs}$ is the observed accumulated burned area for that time period and country. Based on a non-calibrated model run with some initial value of $q = q_0$ and delivering accumulated burned area $A(q_0)$ for a time period for a given country, the respective calibrated value $q_c$ is defined by the following equation:

$$q_c = \frac{-3+\sqrt{24\beta+1}}{2(3\beta-1)}, \text{ where } \beta = \frac{A_{obs}}{A(q_0)}.$$

For the original global application of the model $q_0 = 0.5$ was suggested (Kloster et al. 2010). We apply the country-level calibration procedure described above both in SFM-F and SFM-C forcing the models to fit the reported total accumulated burned area over a time period of several years, which is long enough compared to the model's operating daily time step. An even more advanced spatially explicit (pixel-level) calibration of *q* did not deliver any substantial improvements over the country-level calibration method in terms of country-level aggregated annual burned areas. Even though we did not replace the proxy *q* with a more advanced construction, we made an improvement to the original approach. This modification added spatial variability of suppression potential missing in the original model (Kloster et al. 2010).

**Input data and set up**

For the purposes of this study we exploit two SFM model setups: SFM-F and SFM-C. Since the CLM-AB serves as the data provider for SFM-C, below we explain relevant data sources for both CLM-AB (hence SFM-C) and SFM-F.

*CLM-AB Input Data*

Simulations with CLM-AB were conducted at a spatial resolution of 0.25 degree over a regular Lat/Lon grid for the period 1960-2099. The model runs were performed at half-hourly time steps, and aggregated at a daily time-step. Simulation over the 21$^{st}$ century were conducted with scenarios of aerosol and GHG forcing under the SRES A1B climate change scenario (Nakicenovic and Swart 2000). In this study, CLM-AB was forced by meteorological data from KNMI-RACMO2_ECHAM5, one out of 12 RCM of the ENSEMBLES FP6 RCMs products that showed a temperature and precipitation climate change signal in the middle of the 12 RCMs (Dosio and Paruolo 2011). Temperature and precipitation were bias corrected (Dosio and Paruolo 2011). The meteorological forcing used were: daily average air temperature, precipitation, wind speed, mean sea level atmospheric pressure, global solar radiation incident, and specific humidity. CLM-AB simulations run with transient nitrogen deposition (Lamarque 2005). Atmospheric CO2 concentration (Friedlingstein et al. 2006), and population density scenarios from HYDE dataset followed the SRES A1B scenario.

Because of the lack of lightning scenarios, the mean monthly climatology of LIS/OTD was used, and, therefore, lightning is assumed constant from year to year up to 2099. Although this assumption might be potentially limited for the description of the inter-annual variability of lightning, it can be considered robust because the percentage of fires ignited by lightings in Europe is low (about 5 % according to (Rego et al. 2010b)) compared to the fires ignited by humans. Another dataset used for the purposes of modelling is the EUROSTAT statistics for population density[4] at NUTS3 level. The same data sets were used implicitly in the decoupled version of the model – SFM-C with the exception of population data that is the same as in SFM-F described below.

*SFM-F Input Data*

The fully standalone model SFM-F is using the 50-year (1948-2008) global dataset of meteorological forcing, further referred to as Princeton dataset[5] (Sheffield et al. 2006), which has a resolution of 1 arc degree that is coarser compared to ENSEMBLES data. We used the following subset of available variables: temperature, precipitation, wind, specific humidity, and surface pressure. Relative humidity that is needed for the moisture calculation implemented through FFMC (Van Wagner and Pickett 1985) was derived from temperature, specific humidity, and surface pressure utilizing saturated vapor calculation method suggested by (Flatau et al. 1992).

With SFM-F we investigated possible impacts of climate change and respective adaptation options based on projections provided by different Global Climate Models (GCMs) reflecting the SRES A2 scenario (Nakicenovic and Swart 2000) which is different from that of CLM-AB (SRES A1B). We selected the A1B and A2 scenarios because these medium to high emissions scenarios allow us to analyse relatively large projected changes. However, in this study we did not aim at inter-comparison of a full range of scenarios, or isolating the effects of particular scenarios, or benchmarking particular datasets,

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[4] http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/maps_posters/PER_POPSOC/population

[5] http://rda.ucar.edu/datasets/ds314.0/

we were interested to explore some relatively small subset that is plausible in the adaptation context. For the sake of brevity we present SRES A2 related results based on MRI_CGCM2_3_2A and CNRM_CM3 GCMs. We used historical daily data from Princeton dataset to calculate future daily values based on changes in mean monthly temperature and mean monthly precipitation coming from GCMs and relative to the historical baseline 1961-1970. Changes in mean monthly temperature are added to each day's value to estimate future daily temperatures. Similarly to temperature, changes in monthly precipitation are used to estimate future daily precipitation, yet instead of addition, we multiply historical daily values by a precipitation multiplier to project the value for any day in the future and preserve the number of 'wet' days avoiding the known 'drizzle' effect problem. Projected changes in mean monthly temperature and mean monthly precipitation (Strzepek 2012a; Strzepek 2012b) were estimated relative to the historical baseline (1961-1999) for the three future periods 2026-2035, 2046-2055 and 2086-2095. For the historical period CRU TS 2.1 dataset[6] was used (up-scaled by averaging from 0.5 to 1 arc degree). For future periods the data from IPCC AR4 scenario runs[7] were used (mapped to 1 arc degree). We thank Kenneth Marc Strzepek (strzepek@mit.edu) for providing the projected mean monthly changes data.

In the fully standalone model SFM-F we used Global Forest Biomass map (Kindermann et al. 2008) – a half degree global spatial dataset containing among other variables dead wood and litter carbon required by the fire model. The biomass is static, which is a further simplification compared to SFM-C. In SFM (-F and -C) we make another simplification and do not include lightning as a source of ignition additional to human caused ignitions. This simplification is well justified in the modelling framework for Europe where, as our experiments show, ignition potential explained by relatively high population density entirely overrules ignition caused by lightning which is also in good agreement with (Rego et al. 2010b).

The SFM-C and SFM-F models are calibrated as described above over a nine year period 2000-2008, using statistics reported in the European Fire Database (EFDB) (San-Miguel-Ayanz et al. 2012b) and, as an alternative for comparison, also based on the Global Fires Emissions Database version 3 (GFED) (Giglio et al. 2010; van der Werf et al. 2010). These are different products in terms of spatial extent (regional vs. global), and methods for data acquisition, processing and validation. As the population density dataset we used GPW version 3 (CIESIN 2005).

**Identifying adaptation options and analyzing their effectiveness (step 2)**

In this step we address the challenges of (1) identifying and implementing different adaptation strategies within our modelling scheme applicable at pan-European scale, and (2) simulating the effectiveness of the selected adaptation options for reduction of burned area in the future.

**Identification of adaptation strategies**

There are a number of options available to adapt to anticipated future changes entailing alterations in fire regime. Apart from the most obvious measure – improvement of an active fire suppression – there are also a range of preventive strategies such as prescribed burnings (Silva et al. 2010), management options aimed at restricting the potential spread of fire e.g. utilizing agricultural fields as

[6] CRU TS 2.1 data-set: http://www.cru.uea.ac.uk/~timm/grid/CRU_TS_2_1.html
[7] AR4 GCM data: http://www.mad.zmaw.de/IPCC_DDC/html/SRES_AR4/

fire breaks (Lloret et al. 2002), and long-term options that include increase of rotation length and change of tree species (Schelhaas et al. 2010). The combination of different reactive and preventive measures is also possible and potentially beneficial as it allows for more flexibility and optimization of available resources. Another important aspect is behavioral and connected to the fact that in Europe human activity (including negligence and arson) is the main source of ignitions causing more than 95% of forest fires (San-Miguel-Ayanz et al. 2012a), hence there is a considerable potential in reduction of forest fires by influencing human behaviour, which however is difficult to capture in a model.

This study was focused on a subset of the identified adaptation options, namely active suppression and fuel removal by prescribed burnings. The selected options represent both the immediate actions necessary to protect property and lives – suppression – and preventive measures advocated and promoted already now – prescribed burnings (Silva et al. 2010). A quantitative exploration of the selected adaptation options within the framework of continental scale state-of-the-art fire modelling allows for benchmarking of their potential impact under selected climate change scenarios. However, this selection excludes other options, e.g. setting up fire breaks, improvements in fire detection systems, better distribution and allocation of fire suppression resources, better availability/higher quality of relevant data, or long-term strategies for changing to less fire-prone tree species.

The fire algorithm of CLM-AB (Arora and Boer 2005) aimed at large scale applications is not able to catch such local details as agricultural fields serving as fire breaks. Even though the value of $q$ – the fire suppression proxy parameter - in its present aggregated form can potentially integrate also the fire breaks as they increase the fire suppression probability, the core of the problem is that there is no known quantified empirical relationship between $q$ and fire breaks density. In addition, even though the $q$ proxy can be made spatially explicit, in its present form it does not allow a geographically explicit split-up into comprising factors, such as available fire detection systems and suppression resources (personnel, equipment, water reservoirs, natural barriers for fire, etc.) . A transition to a less fire-prone tree species (e.g. from coniferous to broadleaf) is not handled adequately in the fire algorithm (Arora and Boer 2005) because of a simplified representation of fuel that does not distinguish between different tree species. Many of the above limitations stem from the issue of bridging the small and large scales and emphasize the inherent complexity of the forest fire modelling.

**Implementation of adaptation strategies**

Based on the outcomes of the adaptation options identification and selection process, we focused on modelling of active suppression and prescribed burnings with respect to anticipated climate change within the framework of the fire algorithm (Arora and Boer 2005). The selected adaptation options represent two different approaches – prevention and reaction that are complementary to each other.

The main variables driving adaptation needs in our set-up are those directly influenced by weather. On the methodological side prescribed burnings were simulated by explicitly reducing available fuel biomass both in SFM-C and –F as a consequence of planned preventive fires. Following the fuel representation approach presented in (Migliavacca et al. 2013) we defined fuel available for burning as a combination of litter and coarse woody debris (CWD) pools, excluding stem biomass. For prescribed burnings-induced fuel reduction levels we used the values of 50% for both litter and CWD pools as suggested by (Kloster et al. 2010) for needle leaf trees; since the values for broadleaf trees are higher (60%) our approach is rather conservative.

We model potential improvements in fire suppression through modification of the fire suppression parameter *q* (Eq. 1). There are certain limitations in using the *q* as proxy of the suppression capacity, mainly resulting in difficulties to disentangle detection and response components, and other related factors e.g. setting up fire breaks. As an implication, the current version of the fire module only allows for sensitivity analysis of that aggregated proxy variable *q* rather than of more explicit indicators (e.g. time needed for detection). This limited approach is imposed by the model, yet it is a first pioneering attempt to quantify impacts of reactive and preventive adaptation strategies within one modelling framework at a large scale.

**Analysis of results and stakeholder dialogue (step 3)**

The third step in our analysis involved the analysis of the results and discussing them with stakeholders in the field of fire management and forest sector at two occasions[8]. The aim of these stakeholder consultations was manifold: 1) to receive feedback on the definition, improvement, and evaluation of the adaptation options from experts and stakeholders, and 2) share information about the adaptation policies tested, and 3) to establish and strengthen a dialogue with experts and stakeholders. This step is oriented to the iterative improvement of step 2. Both consultations were hosted by the Expert Group on Forest Fires (EGFF) of the European Commission. This expert group was established by Directorate General Environment (DG-ENV) in association with the JRC with the aim of developing and maintaining of EFFIS, and exchanging information on forest fire prevention practices and lessons learned. The members of the group included environmental associations, Member States of European Union, International organizations and countries outside European Union. More information can be found in the Internet[9].

During the first consultation we discussed, first, the modelling tools, and, second, the qualitative evaluation of the applicability of the different adaptation strategies reviewed in section 0. Together with the participants we agreed and identified the options that can be considered to be more relevant and applicable in a regional to continental context. In particular, experts and stakeholders contributed their experience of management activities conducted in the forest fires sector (European Commission 2010). On the basis of the first consultation we refined our research and modelling approach and finally designed the modelling experiment and the set of adaptation options that needed to be tested. In the second consultation the results obtained were presented and discussed.

**Results and discussion**

[8] The first meeting was organized on November, 11th, 2011, and held at the Joint Research Centre (JRC) of the European Commission (Ispra, Italy) while the second meeting was organized on the 18th-19th , April, 2013, and held at Educational Centre of Administration of the Republic of Slovenia for Civil Protection and Disaster Relief in Sežana, Slovenia.

[9] URL: http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetail&groupID=416.

**Evaluation of modelling accuracy**

*Yearly forest fire dynamics during the historical period*

Here we compare results for SFM-C and SFM-F models, with GFED and EFFIS data reported for the historical period 2000-2008. The setup of the calibration procedure guarantees the exact agreement between simulated and reported country-level burned areas accumulated over the historical nine-year period. The models demonstrated their ability to catch reasonably well the inter-annual variability of burned areas. Figure 8 shows the annual burned areas calculated by SFM-F and -C models against GFED and EFFIS data for Italy and Portugal. Figure 8 (a) shows that for Italy the SFM-F model catches the year-to-year variability quite well ($R^2$ values reported also in Table 6 are 0.44 for GFED and 0.40 for EFFIS). The performance of SFM-C is less convincing for Italy, yet it stays reasonably close to both observational datasets taking into account their disagreement. Figure 8 (b) shows similar results for Portugal, where both SFM models were unable to catch the considerable peaks in 2003 and 2005. This is an example of the well-known limitations of mechanistic fire models that fail to describe well the burned area for years with severe fire seasons (e.g. 2003 and 2005 in Portugal). These limitations are due to incomplete description of fuel/weather interactions, as well as an incomplete description of the suppression probability when multiple fires occur (Migliavacca et al. 2013; Thonicke et al. 2001).

Table 6 reports a more extensive evaluation and inter-comparison of the SFM-C and SFM-F models against GFED and EFFIS burned area data for seven countries: Italy, Portugal, Spain, France, Germany, Poland, and Sweden. An evaluation of GFED with EFFIS data is also reported. To estimate the accuracy of each model we calculate the following fitting indicators: mean absolute error (MAE) and the coefficient of determination, denoted $R^2$ based on annual values for the historical period 2000-2008. Figure 9 reports the scatter plot of observed (with EFFIS and GFED) and modelled annual burned area. Both Figure 9 and the Table 6 show that SFM-F outperforms SFM-C in terms of both MAE and $R^2$, both on GFED and EFFIS datasets, in the majority of cases, and even more: SFM-F provides better agreement with EFFIS data than GFED does. The latter might be due to the fact that GFED products suffer of omission errors when fires are of relatively small size (Kaiser et al. 2012).

*Seasonal dynamics of burned area*

In Figure 10 we present monthly average burned areas for Italy and Latvia for the historical time period 2000-2008 reported in GFED and estimated by SFM-F, -C models (GFED-calibrated). Both models demonstrate a good fit of the monthly data for Italy in Figure 10 panel (a). We reported the seasonal dynamics of observed and modelled burned area in Latvia to highlight some existing difficulties with models' performance. Monthly behaviour observed in GFED data for Latvia (Figure 10 panel (b)), is poorly described by the two SFM models. Monthly GFED data indicates almost no fires in June and July, yet considerable peaks in April and August, which are not followed by the models. In this case, a relatively small burned area may be one of the potential obstacles to the applicability of the SFM models, which have their roots in a larger (global) scale application. Moreover, models do not include any description of fires due to silvo-pastoral management and crop management that often occur in early spring or autumn (Migliavacca et al. 2013; Rego et al. 2010a).

The overall satisfactory results of various validation tests we presented above and also comparison with the outputs of the CLM-AB (Migliavacca et al. 2013) show that the fire module decoupled from the biophysical host model in the way we suggested is capable of delivering reasonable yearly burned area estimates on a country scale in Europe.

**Regional impacts of adaptation strategies**

We analyze the impacts of adaptation options in both temporal and spatial domain. We present firstly, temporal dynamics of burned area in three European regions, and, secondly, the burned area maps for corresponding climate change adaptation scenarios.

*Impacts of adaptation options*

In this section we apply the adaptation strategies described above in section 0 to three European regions: Mediterranean (France, Greece, Italy, Portugal, Spain), the Balkan region and Eastern European Countries (Croatia, Montenegro, Serbia, Slovenia, Slovakia, Hungary, Bulgaria, Macedonia, Czech Republic, Romania), and Central EU and Baltic Countries (Austria, Germany, Belgium, The Netherland, Poland, Latvia, Lithuania, Estonia). In the analysis we use 2000-2008 as the reference period, and three future periods: 2026-2035, 2046-2055, and 2086-2095 for impact and adaptation assessments. We calculate average annual burned areas over these future 10-year time intervals and report those as average values for 2030, 2050, and 2090 respectively, the average value for 2000 was calculated based on the historical period 2000-2008. The SFM-F model with climate projections coming from MRI_CGCM2_3_2A and CNRM_CM3 GCMs is further referred to as SFM-$F_{MRI}$ and SFM-$F_{CNRM}$, respectively. Future projections in SFM-C are based on KNMI-RACMO2_ECHAM5.

Projected impacts and the effect of fuel removal (prescribed burnings) as assessed by the SFM-$F_{MRI}$, SFM-$F_{CNRM}$, and SFM-C models for European regions are presented in Figure 11. For Mediterranean region (Figure 11 (a)) SFM-$F_{CNRM}$ delivers the worst impact under the scenario without adaptation: the yearly average burned area are projected to increase by approximately 3.2 times in 2090 compared to 2000. Both SFM-$F_{MRI}$ and SFM-C project a more moderate increase of about 2.5 times for the same period. Prescribed burnings are projected to decrease the yearly burned areas on average by 74% for the SFM-$F_{MRI}$ and SFM-$F_{CNRM}$ estimations and by 92% for the SFM-C model, in the Mediterranean by 2090.

Yearly burned areas for the Balkan and Eastern European countries are shown in Figure 11 (b). One can see that estimations provided by SFM-C and SFM-$F_{CNRM}$ are very similar. They suggest for the 'no adaptation' scenario an extreme increase of burned areas of about 6.6 times in 2090 compared to 2000, while the SFM-$F_{MRI}$ estimate indicates a comparatively small increase of about 2.5 times. Prescribed burnings are projected to decrease the average yearly burned area in the 2090s by about 47% for SFM-$F_{MRI}$, 69% for SFM-$F_{CNRM}$, and 74% for SFM-C.

Results for Central EU and Baltic countries are shown in Figure 11 (c). In this case the SFM-C model is closer to SFM-$F_{MRI}$, indicating an increase of about 2.2 times in 2090 compared to 2005, while in the SFM-$F_{CNRM}$ model burned areas are projected to increase by 4.4 times. The projected impact of prescribed burnings is rather similar for the three models, decreasing annual average burned areas by about 70%.

In Figure 11 (d) we show the results aggregated for the entire European region including 29 countries (all the regions analyzed above in Figure 11 (a-c)) plus six additional countries: Switzerland, Finland, Sweden, Turkey, Norway, and UK. The figure shows the SFM-C estimate somewhere between those from SFM-$F_{CNRM}$ (with the biggest burned area) and those from SFM-$F_{MRI}$ (with the lowest values). The projected impact of prescribed burnings in the entire European region does not substantially change over the considered future time slices (2030, 2050, 2090) and, in 2090, is about 65% for SFM-$F_{CNRM}$, 67% for SFM-$F_{MRI}$, and is the highest for the SFM-C model, where prescribed burnings lead to a projected reduction of the average burned area by about 86%.

The results of our study in terms of the estimated impact of prescribed burnings on burned areas are in line with other studies on the effectiveness of prescribed burning for fire hazard reduction. (Fernandes and Botelho 2003) reviewed the effects of prescribed burning in the US showing a difference of about 3 times between the average size of a wildfire in areas treated within the last 3 years and the size in untreated areas (8.5 ha vs. 25.2 ha). Also, (Fernandes and Botelho 2003) refer to Australia where the average wildfire size burning in treated areas within less than 3 years was reported to be 50% smaller (reported to be 302 ha as opposite to that of 584 ha outside of treated areas). Even though we did not explicitly model the treatment frequency component in our models, the effectiveness of the measures we observe from our modelling seem to be well comparable with the values reported in the literature, especially taking into account our possible overestimation stemming from the simplified assumption that fuel removal will occur everywhere. Another approach is presented in the literature for the case-study of the pine forest of north-western Portugal (Fernandes and Botelho 2004), where the effectiveness of prescribed burnings is measured against the resources needed to put out a fire e.g. a crew with minimum equipment may be able to handle up to 97% or 64% of the cases in pre-treated areas under normal and extreme weather conditions respectively (as compared to only 24% and 0% without any pre-treatment).

We further analyzed how the change in suppression strategies, described in terms of the proxy parameter *q* (calibrated at a country level as described above), impacts the accumulated burned areas. We performed sensitivity analysis by varying this proxy, aggregating a country's fire suppression abilities. A country specific burned area corresponding to a calibrated *q* value is taken as unit value, and changes in burned areas with respect to ±10% changes in *q* are estimated and presented in Figure 12 for both SFM-F and SFM-C, calibrated using GFED data for eight selected countries. Since the calibrated country-specific values of *q* differ for the two models, the plots show slightly different ranges of respective burned area change for the same country. In general, a relative change of *q* by ±10% leads to a relative change in burned areas by ±30%. This relative change depends on the initial value of *q* and results in wider ranges for bigger values. An increase of *q* can be interpreted as improvement of an active response to forest fires in a region, and leads to a decrease in the burned area.

In our modelling framework fire suppression is not limited to a particular technique and potentially might include the use of fire itself e.g. backfire, burning out, counter firing (Silva et al. 2010). Even though preventive measures (fuel removal) were handled explicitly, the improved suppression was described only through a proxy variable aggregating detection, resource availability and management. The existing modelling framework does not allow for separation of those different factors. Comparison between the marginal efficiency of improving suppression versus marginal efficiency of introducing more prescribed burnings in the sense of burned area reduction cannot be duly carried out in this framework because of, on one hand, a general nature of *q* and opposed to it specific definition of prescribed burnings, and on the other hand, because of the missing cost component. However, the presented framework allows for the assessment of a combined application of both modelled adaptation options because the model parameters relevant to prescribed burnings (fuel removal) and improved suppression are separable from each other i.e. their respective burned area reduction factors multiply in case of a combined application.

*Spatially explicit impacts of fuel removal*

For illustration purposes we present the maps that show the comparison of SFM-F model outputs with GFED data for 2005, and that also highlight the impact of prescribed burnings (fuel removal) in 2090 (Figure 13). For this analysis we apply spatially explicit (pixel-level) calibration of *q* mentioned in the section 0. One can see from Figure 13 (GFED 2005 and SFM-F 2005 panels) that the model approximates reasonably well the yearly accumulated GFED data for our case study area. However, there are some visible discrepancies in some countries to the eastern boundaries of European Union (Ukraine and Turkey). The $SFM\text{-}F_{MRI}$ and $SFM\text{-}F_{CNRM}$ models (GFED-calibrated on the historical period 2000-2008) estimate the average burned area in 2090 under the no-adaptation and the prescribed burnings scenarios. The maps demonstrate that prescribed burnings may considerably decrease burned area in European region in the future.

**Conclusions**

In this paper we presented a framework for assessing the potential effectiveness of two adaptation options: (1) prevention through fuel reduction via prescribed burnings, and (2) active response through better fire suppression. We presented the first model-based quantification of the potential effectiveness of prescribed burnings with respect to anticipated climate change on a pan-European scale.

The two options that we explored were discussed and selected in consultation with stakeholders, because, first, at a higher level of abstraction they represent two classes of approaches – prevention and reaction – and at the same time allow meaningful quantification and interpretation. Second, these options are realistically applicable at pan-European scale and, third, can be handled within the state-of-the-art large scale fire models. Other relevant options, such as increasing land fragmentation and species conversion (needle leaf forest to deciduous) cannot be properly modelled within the selected framework, because, first, the fire spread is not governed by the fragmentation of landscape, and second, because of a simplified representation of the fuel.

The quantitative results we obtained show satisfying models' performance in terms of agreement of the modelled burned areas in Europe with observed data coming from different sources (EFFIS and GFED). Moreover, our projections and assessments of adaptation options are in line with existing literature. Our estimation of potential increase of annual burned areas in Europe under a high-emissions "no adaptation" scenario is about 200% by 2090, compared to 2000-2008. The application of prescribed burnings has a potential of keeping that increase below 50%. Improvements in fire suppression might reduce this impact even further, e.g. boosting probability of putting out a fire on a day by 10% country wide would result in about 30% decrease of annual burned area for that particular country. Since we did not include all potentially available adaptation options into our analysis, such as agricultural fields acting as fire breaks, behavioural change and long-term options like replacement of forest species, the effects of climate change can potentially be reduced beyond these indicative levels. Future efforts should be oriented at exploration of relevant costs and benefits that would ultimately define the feasible level of the impact reduction.

The needs for relaxing the current modelling limitations identified in the course of this research call for a fundamental refinement of the existing continental-scale fire models. Making this major step, however, is beyond the scope of the presented research and therefore is left for future elaborations.

**Tables:**

*Table 6. Inter-comparison of the burned areas from SFM-C and SFM-F models (using both GFED and EFFIS data for calibration) for seven countries: Italy, Portugal, Spain, France, Germany, Poland, and Sweden - mean absolute error (MAE) and the coefficient of determination ($R^2$)- based on annual values for the historical period 2000-2008.*

| Country | SFM-F (GFED) vs GFED | | SFM-C (GFED) vs GFED | | SFM-F (EFFIS) vs EFFIS | | SFM-C (EFFIS) vs EFFIS | | EFFIS vs GFED | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $R^2$ | MAE | $R^2$ | MAE | $R^2$ | MAE | $R^2$ | MAE | $R^2$ | MAE |
| Italy | 0.438 | 2.69E+04 | -0.723 | 5.08E+04 | 0.402 | 2.92E+04 | -0.562 | 5.00E+04 | 0.354 | 3.47E+04 |
| Portugal | 0.247 | 1.08E+05 | -0.42 | 1.51E+05 | 0.301 | 8.00E+04 | -0.372 | 1.30E+05 | 0.87 | 2.97E+04 |
| Spain | 0.41 | 2.63E+04 | -1.423 | 4.87E+04 | 0.452 | 2.96E+04 | -1.601 | 5.95E+04 | 0.408 | 3.18E+04 |
| France | 0.266 | 5.35E+03 | -1.638 | 8.77E+03 | 0.456 | 1.14E+04 | -2.572 | 2.32E+04 | -0.236 | 1.54E+04 |
| Germany | -0.101 | 2.11E+03 | -0.183 | 1.94E+03 | 0.633 | 1.42E+02 | -1.72 | 2.97E+02 | -184.581 | 1.36E+03 |
| Poland | 0.157 | 2.45E+03 | -0.358 | 3.36E+03 | 0.323 | 4.61E+03 | -0.329 | 7.06E+03 | -0.046 | 6.04E+03 |
| Sweden | -0.121 | 1.49E+03 | -0.346 | 1.89E+03 | -0.015 | 1.51E+03 | -0.942 | 1.90E+03 | -1.696 | 2.08E+03 |

**Figures:**

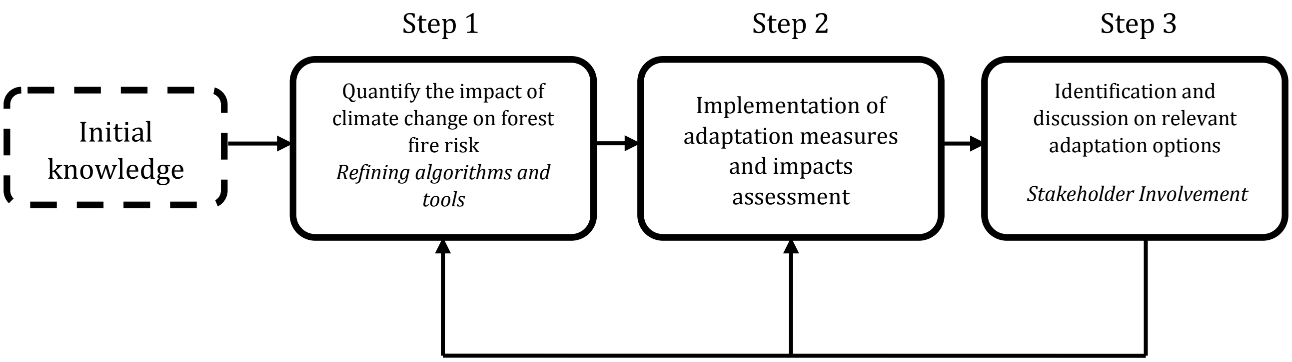


*Figure 7. Schematic diagram of the methodology followed to address the questions regarding adaptation options to forest fires in Europe.*

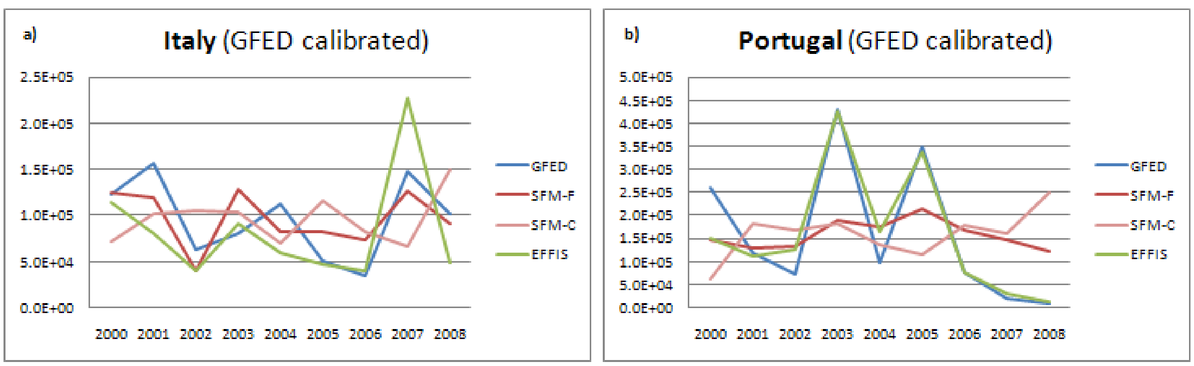


*Figure 8. Annual burned areas (hectares) for Italy (a) and Portugal (b) estimated by SFM-F and SFM-C models both calibrated using GFED dataset compared against GFED and EFFIS data.*

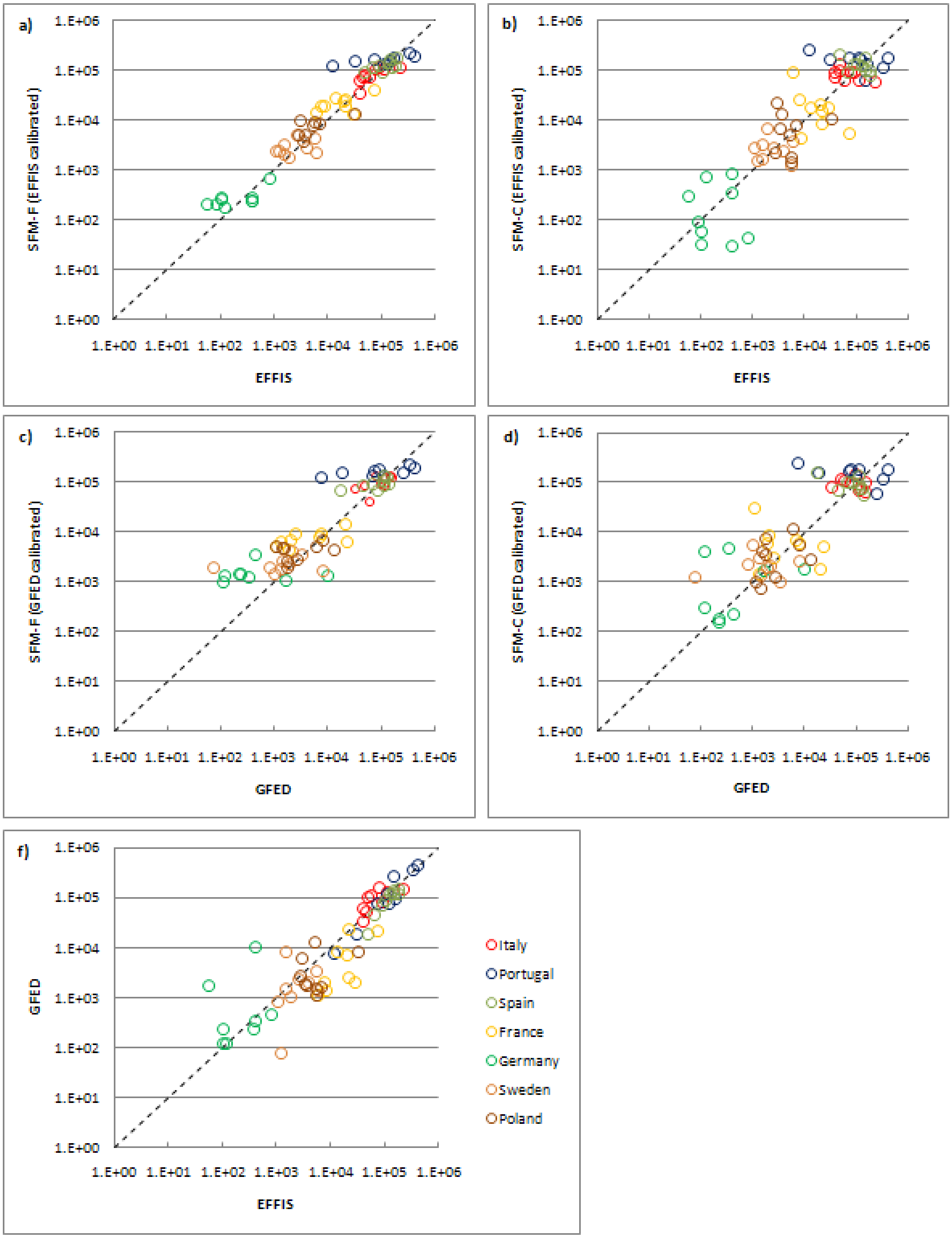


*Figure 9. Scatter plots of yearly burned areas (models vs. reported and GFED vs. EFFIS) in hectares on a log scale. Circle colors correspond to countries.*

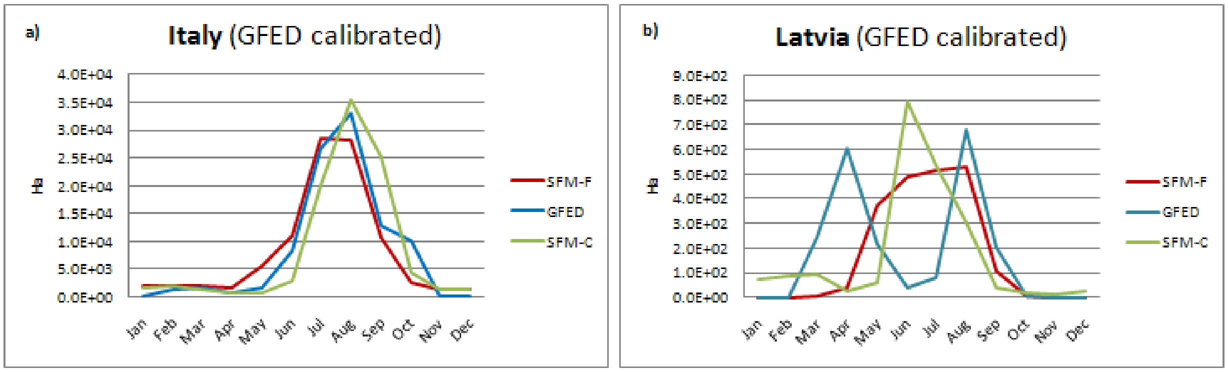


Figure 10. Monthly average burned areas (hectares) for Italy and Latvia for the historical time period 2000-2008 reported in GFED and estimated by SFM-F, -C models (GFED-calibrated).

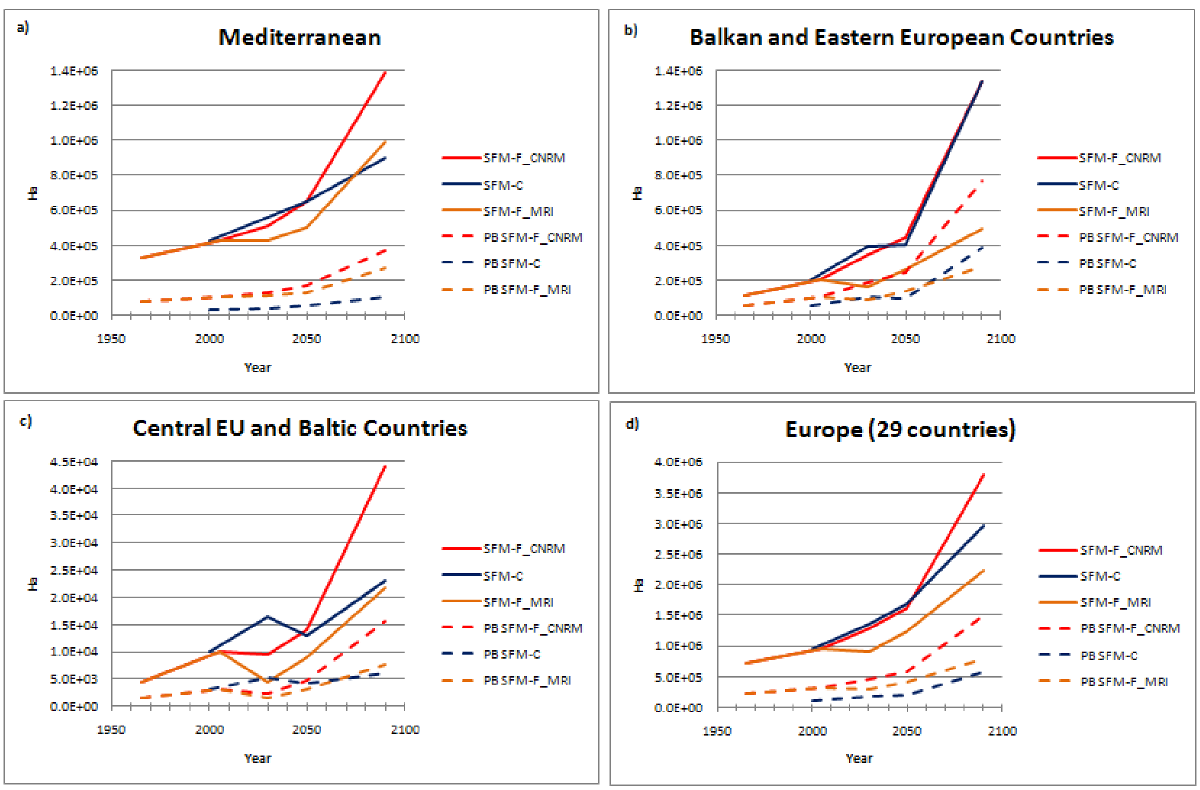


*Figure 11. Projected impacts and effect of fuel removal (prescribed burnings) on burned areas (in hectares) as assessed by SFM-$F_{MRI}$, SFM-$F_{CNRM}$, and SFM-C models for European regions. Solid lines represent no adaptation scenario, dashed lines – prescribed burnings (PB).*

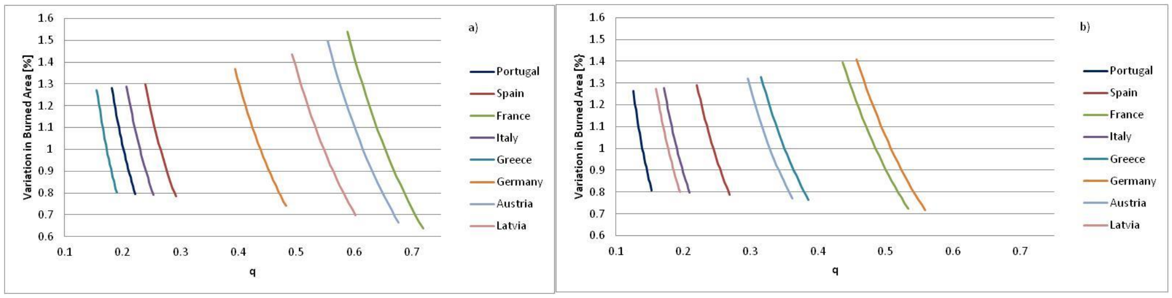


*Figure 12. Sensitivity analysis of suppression efficiency for GFED-calibrated models SFM-F (panel a) and SFM-C (panel b). Change in burned areas are relative to calibrated value of q (unit value) when q varies within ±10% range.*

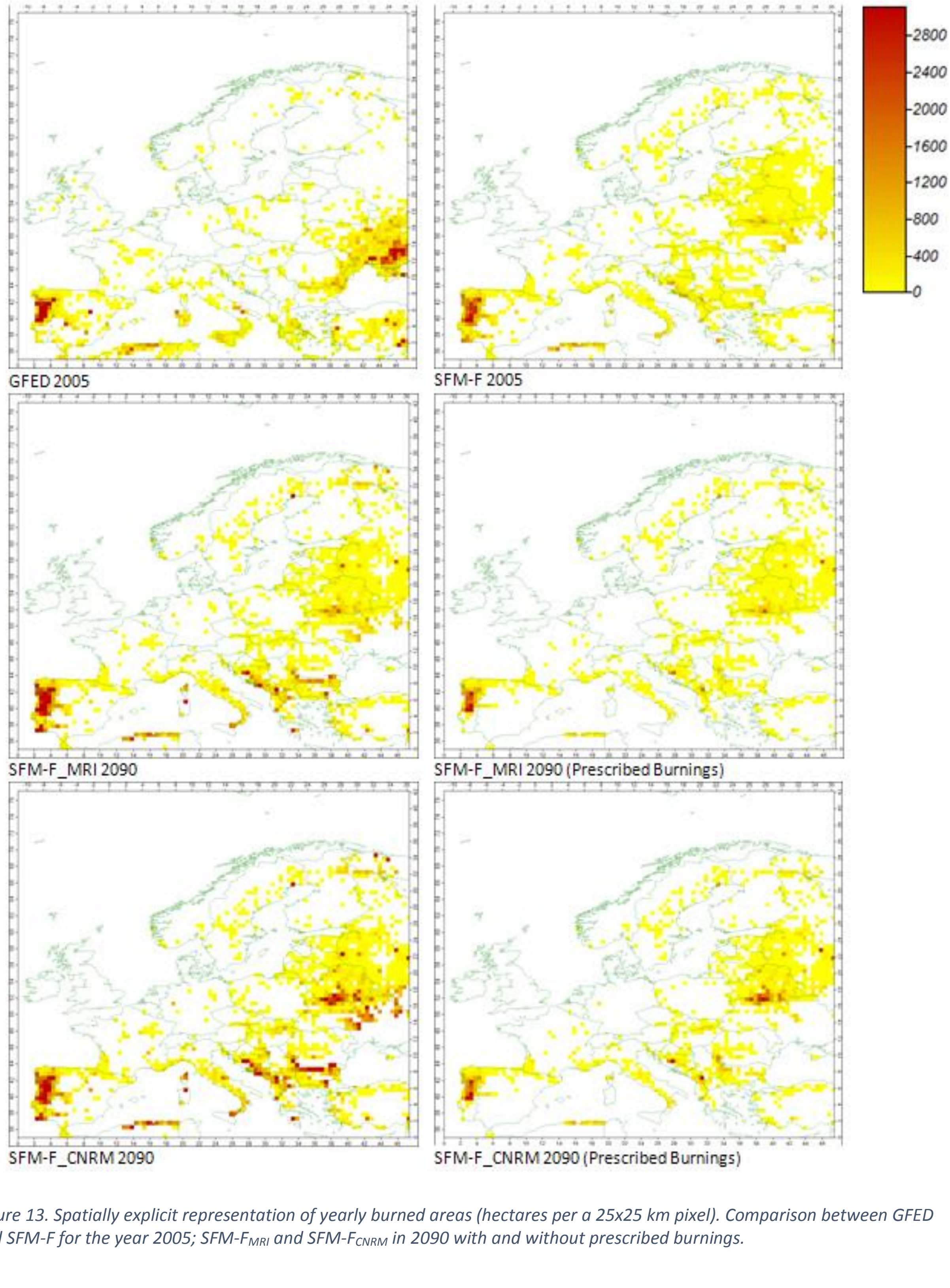


*Figure 13. Spatially explicit representation of yearly burned areas (hectares per a 25x25 km pixel). Comparison between GFED and SFM-F for the year 2005; SFM-$F_{MRI}$ and SFM-$F_{CNRM}$ in 2090 with and without prescribed burnings.*

## The elderly in Nordic countries

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### 1 Introduction

The objective of this study is to identify and map quantitative measures of vulnerability of the elderly to extreme weather associated with climate change at municipality scale in Norway, Sweden and Finland. The origins of this work arise out of CARAVAN[10], a two-year collaborative Nordic project (2008-2010). The work has subsequently continued as part of the nationally-funded MAVERIC[11] and European Commission-funded MEDIATION[12] projects.

#### 1.1 Extreme weather events and the elderly

Elderly people are one of the groups that are especially vulnerable to a range of weather-related hazards such as heat waves, icy conditions, cold periods and storms. Even in unexceptional years, it has been estimated that an extra 2000-3000 deaths occur on average in Finland each year in the cold season (relative to annual mean mortality), with the great majority among persons aged 65 and older (Näyhä, 2005). Slippery conditions associated with icy pavements have been shown to provide a partial explanation of wintertime excess of distal radius (forearm) fractures among elderly women in Finland (Flinkkilä et al., 2010). Heat wave events can result in significant excess morbidity and mortality among the elderly, mainly attributable to cardiovascular or respiratory failure (Åström et al., 2013; Rocklöv and Forsberg, 2009). For example, approximately 55,000 excess deaths were recorded in the 2010 Russian heat wave, primarily among the elderly (Barriopedro et al., 2011). The latter event extended to eastern Finland, with an excess mortality of about 400 recorded nationally in July 2010 (Ruuhela, 2012, p. 112), while an earlier event in 1972 resulted in about 800 excess deaths in Finland (Näyhä, 2005). Similar heat wave excess mortality has also been recorded in Sweden (Rocklöv and Forsberg, 2008).

The coping capacity of the elderly to respond to extreme weather can also be limited (e.g., through impaired mobility, isolation, and poor access to health and welfare services, O'Neill et al., 2009). For

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[10] CARAVAN (Climate change: a regional assessment of vulnerability and adaptive capacity for the Nordic countries) was funded by the Academy of Finland, Research Council of Norway and Swedish Environmental Protection Agency in the Nordic-Call of CIRCLE (Climate Impact Research Coordination for a Larger Europe), an ERA-Net project established under the European Commission Sixth Framework Programme, see: http://www.circle-era.eu/np4/home.html
[11] MAVERIC (Map-based assessment of vulnerability to climate change employing regional indicators) project, January 2009 – December 2012 (Academy of Finland).
[12] MEDIATION (Methodology for Effective Decision-making on Impacts and AdaptaTION) project, January 2010 – June 2013 (European Commission, Sixth Framework Programme).

instance, a failure of basic health and welfare monitoring was a contributing factor in the large numbers and central Europe in 2003 (Le Tertre et al., 2006; Robine et al., 2008).

### 1.2 extreme weather events

Future climate change is expected to alter the frequency and magnitude of certain types of weather events in the Nordic region. The most recent IPCC assessment of extreme events (Seneviratne et al., 2012) reported high confidence in climate projections for a wider northern European region, based on multiple model-based sources (Table 1 – see caption for explanation of likelihoods). These projections indicate a very likely increase in frequency of high temperature extremes and decline in frequency of low temperature extremes during the 21st century, in line with changes already observed (with medium confidence) during the 20th century. Heat waves are likely to be more frequent, longer and/or more intense, though summer changes may be relatively small over Scandinavia. Heavy precipitation events are very likely to increase in winter (Table 1). In addition, it is likely that there has been a poleward shift in mid-latitude, extra-tropical storm tracks during the last 50 years, with medium confidence that this shift will continue due to future anthropogenic forcings (Seneviratne et al., 2012).

**Tables**

**Table 1. Summary of selected changes relative to the late 20th century in extreme temperature and precipitation indicators for northern Europe* observed since 1950 and projected for the late 21st century. Source: Tables 3.2 and 3.3 and Figure 3.5b in Seneviratne et al. (2012). Confidence statements are based on expert evaluations that consider the robustness of evidence and analyses. Likelihood assessments of a direction of change are provided only for assessments with high confidence (*Very likely* = 90-100%; *Likely* = 66-100%).**

| Extreme indicator | Observed changes (ca. 1950 to late 20th century) | Projected changes** (late 20th century to late 21st century) |
|---|---|---|
| **Daily maximum temperature (Tmax)** | **Medium confidence**: Increase in warm days; decrease in cold days. Consistent signals for whole region, but generally not significant at the local scale | **High confidence**: *Very likely* increase in frequency of warm days (smaller than in C. and S. Europe); 1-in-20 year annual hottest day is *likely* to become a 1-in-5 year annual extreme; *Very likely* decrease in cold days |
| **Daily minimum temperature (Tmin)** | **Medium confidence**: Increase in warm nights; decrease in cold nights. Consistent signals for whole region, but generally not significant at the local scale | **High confidence**: *Very likely* decrease in frequency of cold nights; *Very likely* increase in warm nights |
| **Heat Waves/ Warm Spells** | **Medium confidence**: Increase in heat waves. Consistent tendency for increase in warm spell duration index, but no significant trends | **High confidence**: *Likely* more frequent, longer and/or more intense heat waves and warm spells, but summer increases less than in S. Europe and little change over Scandinavia |
| **Heavy Precipitation** | **Medium confidence**: Increase in winter in some areas, but often insignificant or inconsistent trends at sub-regional scale, in particular in summer | **High confidence**: *Very likely* increases in heavy precipitation (intensity and frequency) north of 45°N in winter |

*Polygon with corner co-ordinates: (48°N,10°W; 75°N,10°W; 61.32°N,40°E; 75°N,40°E). ** Based on outputs of multiple general circulation models (GCMs) and multiple regional climate models forced by multiple GCMs

### 1.3 Defining vulnerability

The concept of vulnerability is widely applied in climate change research (Patt et al., 2009), but it is framed in contrasting ways (Füssel, 2010b; Preston et al., 2011) and its definition has been subject to refinement over time (e.g., Lavell et al., 2012).

For instance, Preston et al. (2011) identify four approaches (labelled "models") for framing vulnerability of a system or process to climate change. Risk-hazard approaches emphasise exposure and sensitivity to biophysical risk factors like climate change, but tend to ignore the socio-economic aspects of adaptive capacity that can influence system sensitivity and hence vulnerability. Social vulnerability approaches, in stark contrast, focus on the vulnerability of the system to socio-economic pressures (often referred to as adaptive capacity) but ignore information on biophysical stresses such as climate change. Pressure-and-release (PAR) approaches attempt to combine the above two approaches, by treating risk as a function of the biophysical hazard and the adaptive capacity of the system. Fourth, the expanded vulnerability (EV) approach, acknowledges that the vulnerability of a system can also be affected by processes and feedbacks operating at different spatio-temporal scales.

In light of these alternative approaches, the Intergovernmental Panel on Climate Change (IPCC) has altered its definition of vulnerability from a more specific formulation:

"Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity." in the Fourth Assessment (IPCC, 2007 Adaptation, p. 883), itself slightly modified from the Third Assessment (IPCC, 2001 Adaptation, p. 995), to a more generic definition:

"The propensity or predisposition to be adversely affected". in the Special Report on Extremes (IPCC, 2012, p. 564). Some researchers, finding the term vulnerability to be potentially confusing, simply avoid using it altogether, adopting an alternative descriptor instead. For instance, Füssel (2010a) refers to social impacts of climate change as the comparative measure of vulnerability in a review of global indicator-based assessments.

**1.4 Vulnerability mapping**

One of the most popular devices for portraying vulnerability to climate change is through maps. Vulnerability maps are constructed by first identifying key indicators thought to contribute to the vulnerability of a target system (such as a population, ecosystem or institution) to climate change. Indicators are measured or modelled attributes for which spatially distributed data are available for geographical units across a region. Selecting from a variety of techniques to standardise the data, these quantitative indicators may be combined into a vulnerability index, a composite measure that can also be mapped. Examples of such exercises abound in the literature, ranging in spatial scale from global (Diffenbaugh, 2007, Indicators of, and see review by Füssel, 2010b; Yohe et al., 2006), through continental (Greiving et al., 2011; Lung et al., 2013; Metzger et al., 2008), to national (O'Brien et al., 2004a; O'Brien et al., 2004b) and sub-national (Swart et al., 2012) studies.

Indicators and indices of vulnerability have been widely reviewed in the literature (e.g., Malone and Engle, 2011; Polsky et al., 2007; Preston et al., 2011). A mapped characterisation of relative vulnerability to climate change can be visually alluring as a quick method for comparing circumstances in different regions, but an index combining multiple attributes can also pose problems of interpretation, transparency and robustness. Unlike estimates of future climate change impacts, which usually involve formalised modelling of cause-effect relationships between climate determinants and the system affected by climate, vulnerability indices commonly rely upon judgements of causality, where indicators are selected if they are believed (often subjectively) to offer a measure of vulnerability to climate change, and then combined (often arbitrarily) into indices. These "conceptual, methodological, and/or empirical deficiencies" (Füssel, 2010a) have led to serious challenges of the vulnerability mapping approach as a scientifically credible analytical method (and see Hinkel, 2011). Moreover, the emergence of vulnerability indices that are being offered as risk assessment services by the private sector, but with no publicly available, peer-reviewed documentation of the methods applied (for example, the climate change vulnerability index produced by Maplecroft Global Risk Analytics[13]) can only contribute to a mistrust of such indices.

In light of the preceding critique of vulnerability indices, it may appear incongruous that the study presented in this paper introduces a tool for mapping climate change impacts and vulnerability. Furthermore, the tool makes use of some of the same analytical methods decried above. However, it is argued here that there can be a useful role for such mapping, as long as the underlying purpose, data and assumptions are fully transparent to the audience. The specific case to be examined concerns the potential impacts of future climate change on the elderly population in the Nordic region – manifest through changes in climatic variability, including weather extremes – and possible adaptation options to ameliorate such impacts. While an underlying motivation of the work is to highlight vulnerability of the elderly, the conventional method of characterising vulnerability is extended and re-framed in terms of potential impacts and adaptation. The study is presented according to a set of analytical steps that were followed from the initial posing of an adaptation-related research question, through selection of methods, development of a mapping tool and refinements on the basis of iterative exchanges with stakeholders. This stepwise assessment is in common with other case studies undertaken and analysed at different scales in Europe for the MEDIATION project.

The next section presents first, the overall approach adopted in the study, including an attempt to recast elements of vulnerability in the context of impact assessment and adaptation. This is followed by a description of the analytical methods and data sources used in developing a mapping tool for exploring vulnerability of the elderly to climate change in the Nordic region. Section 3 presents examples of different aspects of the mapping tool, illustrating the general set up, input data and their manipulation, some key assumptions, a taste of the types of outcomes that can be generated and some results from stakeholder interaction. The final section then reports some of the lessons learnt from the study and suggests possible future extensions to the mapping tool, offering a number of arguments in support of the approach, tempered with appropriate caveats.

## 2 Materials and methods

### 2.1 Analytical steps

This is one of a number of case studies undertaken in the MEDIATION project, highlighting different methods of climate change adaptation assessment. The objective of the study, as outlined in the introduction, is to assess the vulnerability of the elderly population to risks from extreme weather under a changing climate in the Nordic region. This objective was defined by the research team based on

[13] http://maplecroft.com/about/news/ccvi_2013.html

knowledge of ongoing trends towards an ageing population, recent observed incidences of excess mortality among elderly populations during severe heat waves in different parts of Europe, and projections of future warming of the climate, with an associated increase in frequency of high temperature extremes. By drawing attention to possible enhanced vulnerability to heat waves in the future, as well as to regional differences in this vulnerability across the Nordic region, it was hypothesised that national and regional decision-makers responsible for the care of the elderly might be alerted to consider possible adaptive measures required in light of the changing risks.

In common with the other MEDIATION case studies, this assessment can be broken down into a number of analytical steps. Five main steps have been identified, with a question posed at each step ( Figure 1):

- Step 1 (What do we already know?) involved drawing together evidence from the published literature to demonstrate the susceptibility of elderly people to weather-related extremes in general, and specifically in the Nordic region. This background information was summarised above, in Section 1.1.
- Step 2 (What climate-related risk factors do the elderly face?) comprised a detailed literature review to identify those factors known or suspected to be most important in contributing to adverse impacts of weather events on the elderly population at present, as well as likely contributory factors to altered risks of impacts in the future. This information defined the types of variables and resolution for which data would be required in order to quantify future risks. It also formed the basis for the design of different analytical methods applied to determine future vulnerability and impacts.
- Step 3 (How does vulnerability vary regionally?) involved developing a framework for collecting relevant data identified in Step 2 for the Nordic region, storing these in a database and offering options for producing regional maps of the original data or of combinations of these. In this case, the pilot version of an interactive web-based mapping tool was developed in Step 3, with an understanding that this version would be subject to revision and updating following feedback from users.
- Step 4 (Is the vulnerability mapping tool of interest?) was the point at which initial contacts were made with key stakeholders, defined as persons concerned with the provision of care, facilities and resources for the elderly at national and regional scale in the Nordic region. Two approaches were employed: interviews and a workshop, the latter being the forum in which the web tool was first presented. The interviews and feedback from the workshop provided valuable sources of feedback on the utility of the web tool as well as a range of perspectives on potential climate change impacts, vulnerability and adaptation.
- Step 5 (How could the mapping tool be improved?) represented the first major iteration in the study, where feedback from key sectoral stakeholders as well as other researchers provided a basis for refining the methods of mapping future impacts and vulnerability, adding a model of heat wave mortality, extending the treatment of uncertainties, and providing more information on adaptation options.

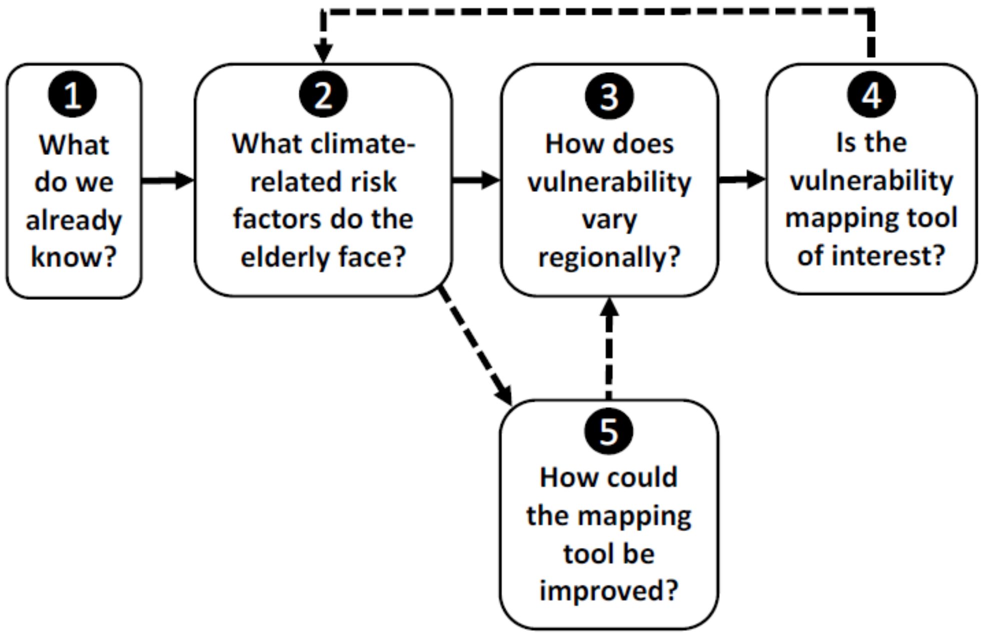


**Figure 1 The five main steps employed in this study, with interations shown by dashed arrows.**

The remainder of this paper describes the overall framing, methods and some findings from steps 2-5. Much of the work conducted in the MAVERIC and MEDIATION projects was carried out as the iteration from step 4 to step 5, focusing on Finland but also refining the Nordic-wide analysis initiated during the earlier CARAVAN project (steps 1-4). Aspects of this iteration are also reported in more detail elsewhere (Terämä et al., In preparation), so are only alluded to in this paper.

### 2.2 Impacts, adaptation and vulnerability

The paper presents two approaches for representing potential impacts of the elderly to future climate change in the Nordic region and possible options for adaptation. The first approach (Step 3 in Figure 1) is indicative, based on the identification, mapping and combination of variables (indicators) believed to predispose the elderly to adverse impacts. The second approach (added in Step 5) is definitive, focusing on an extreme metric of climate change impact on the elderly – premature mortality – and modelling its dependence on temperature. Hence, the former approach characterises potential vulnerability to adverse impacts, while the latter describes realised vulnerability in terms of one type of adverse impact.

In Appendix 1 an attempt is made to reconcile these "vulnerability" and "impact" approaches by expressing both as a function of exposure and sensitivity to climate change, each of which can be mediated by adaptation. The specification of adaptation is one way of distinguishing a vulnerability approach from an impact approach. In the former, the potential for adaptation is represented using indicators of adaptive capacity. These are combined with indicators of exposure and sensitivity in a vulnerability index (equation 5). In the latter, adaptation can be modelled explicitly as a modifier of model inputs or parameter values expressing the exposure or sensitivity to climate change (equation 8).

A second aspect of projecting impacts of future climate, which is also explored in this paper though commonly overlooked in many other studies, is the characterisation of future socio-economic conditions. These are trends that might themselves influence future vulnerability and impacts regardless of future climate change (T in equation 8, Appendix 1).

Finally, a third issue to be addressed in this study is the representation of uncertainty in impact projections. Alternative projections of climatic and socio-economic conditions are represented both by scenarios and, in some cases, probabilistically. Climate projections span a range of emissions assumptions defined by the IPCC Special Report on Emissions Scenarios (SRES – IPCC, 2000), which although not explicitly including climate policy, can be used as surrogates for mitigation scenarios at the lower end of the range. Mitigation of climate change is another of the options for adjusting exposure in the formulation presented in Appendix 1 (ΔCM in equation 8).

### 2.3 Vulnerability mapping for the Nordic region

The conventional framing of vulnerability to climate change – as a function of exposure, sensitivity and adaptive capacity (Appendix 1, equation 5) – formed the basis for a series of vulnerability mapping exercises that were initiated at the turn of the millennium (see above). Among these was a study exploring vulnerability to climate change at different scales in Norway (e.g., O'Brien et al., 2006; O'Brien et al., 2004b; Sygna et al., 2004). The outputs of that work included a number of mapped indices combining variables identified as important for the exposure and adaptive capacity of Norwegian agriculture (O'Brien et al., 2006) and sensitivity of winter tourism (Sygna et al., 2004) to climate change.

In a follow-up study of climate change vulnerability for the Nordic region (CARAVAN – Carter et al., 2011), the same approach was adopted to map indicators of vulnerability at the municipality scale for Norway, Sweden and Finland. The main rationale for extending this analysis was that the challenges of climate change are similar across the different countries and might warrant a regional approach to strategies of adaptation response. A web-based, interactive mapping tool was developed for depicting vulnerability indicators and allowing these to be combined by a user into composite indices[14]. As a "proof of concept" in designing the tool, it was decided first to focus on agricultural vulnerability, using the same indicators that had been applied in the earlier Norwegian study. Although the results of that exercise are not the focus of this paper, some of the lessons learnt during the process of data acquisition and tool development are relevant to the present study too and discussed below. Here we concentrate on the development of the tool as it applied to vulnerability of the elderly.

#### 2.3.1 Vulnerability indicators (Step 2)

A literature review on the vulnerability of elderly people to adverse effects of the weather was undertaken to provide some background information for the selection of indicators. Factors thought to affect exposure, sensitivity and adaptive capacity were treated separately.

*Factors affecting exposure*

Some of the key weather hazards that contribute to exposure of the elderly to possible adverse impacts were discussed in sections 1.1 and 1.2, above. Numerous indicators of significant (not necessarily extreme) weather events exist in the literature (e.g. Beniston et al., 2007; Frich et al., 2002; Seneviratne et al., 2012), and for the purposes of this study three classes of hazard associated with known impacts on the elderly were defined: exposure to heat-related events, to cold-related events and to icy

[14] http://www.iav-mapping.net/CARAVAN/CARAVAN.html

conditions. Candidate indicators were then identified for which both observations and projections of future changes were available across the Nordic region. Exposure to climate change was described as the change in frequency of events between 30-year periods (to capture the statistical properties of the weather) at the present and in the future (around 2040). This required information both on observed and projected climate (see section 2, below).

A second dimension of exposure is the population at risk of impact. Here, the elderly population was defined according to official national criteria as persons aged 65 and over in Sweden and Finland (67 in Norway). As the proportion of the elderly in the population is expected to increase rapidly in the future, detailed regional projections of population were also required. Note that in the original CARAVAN study, the elderly population was considered as an indicator of adaptive capacity, along with all other socio-economic variables. However, it has been re-assigned as an exposure indicator in the present study, in line with most earlier interpretations (e.g. Nicholls et al., 2008).

*Factors affecting sensitivity*

Some of the important factors contributing to the present-day sensitivity of elderly people to harm from common hazards, including weather-related events, can been listed as follows (O'Brien and Leichenko, 2007; OECD, 2006): age (i.e. the progressive loss of psychological resilience with increasing age), deterioration of health (e.g. cognitive and visual impairment, medical drug use), personal lifestyles (e.g. insufficient physical exercise, inappropriate assistive devices), poorly designed and inadequate infrastructure (e.g. building materials, density and accessibility; green spaces), loneliness (including isolation and inadequate social networks), poverty (affecting the ability, willingness or wherewithal to maintain a safe living environment), and inadequate health or social structures (limiting preventative or remedial interventions).

*Factors affecting adaptive capacity*

Finally, factors affecting the adaptive capacity to ameliorate adverse impacts in the future have also been identified (Koppe et al., 2004; O'Brien and Leichenko, 2007; OECD, 2006): uncertainties regarding the future health conditions of the elderly, level of participation of elderly people in economic activity (i.e. risks associated with their enhanced physical and cognitive impairments compared to younger employees), future welfare and income, patterns of care, and changes in the private sphere (e.g. family relations, divorce rates, childlessness and single households).

*Selecting the indicators*

Using the above factors as a guide, a candidate set of indicators of vulnerability was compiled for which spatially distributed information could be obtained or derived. Several criteria were then used to select from the longer list of variables identified:

- availability of observed, statistical (sampled), or model-based data collected at or interpolated to municipality scale;
- data representing present-day and, if possible, future conditions;
- relevance of the indicator in all three Nordic countries;
- availability of comparable data across all three countries: Finland, Norway and Sweden.

In addition, it was decided to merge sensitivity with exposure in developing the mapping tool. Since the focus is on vulnerability to climate change, for the purposes of this study a simple assumption is made that sensitivity of the elderly exposed to weather events in the future remains unchanged from that at the present-day. Of course, this is unlikely to be the case in reality, as the fitness and general resilience of the population in the future is likely to improve, as it has historically. However, such adaptations are assumed to be captured adequately by the indicators of adaptive capacity. The final set of indicators applied in the study, along with their primary sources, are hence classified either as indicators of exposure/sensitivity (Table 2) or of adaptive capacity (Table 3).

**Table 2 Indicators of exposure for characterising vulnerability of the elderly to climate change (sensitivity is included implicitly)**

| Indicator | Units | Description | Effect on exposure | Source |
|---|---|---|---|---|
| **Potential heat stress** | | | | |
| Change in the number of high temperature days | Days/ year | Change in the number of high temperature days between 1971-2000 and 2021-2050 when the daily mean temperature exceeds the 99th percentile of the temperatures observed during 1971-2000. | Positive: As the number of high temperature days (relative to the normal local range) increases, elderly people become more susceptible to heat stress | 1, 2 |
| Change in the number of very warm days | Days/ year | Change in the number of very warm days between 2021-2050 and 1971-2000. A very warm day is defined as a day when the daily maximum temperature is above 25°C. | Positive: As the number of warm days (defined consistently in all regions) increases so the risk of heat stress among the elderly increases. | 1, 2 |
| Relative change in the number of heat waves | Scalar | Relative change in the number of heat waves between 1971-2000 and 2021-2050. A heat wave is defined if the daily mean temperature exceeds the 99th percentile of the 1971-2000 daily mean temperatures (defined locally) over an interval of at least 6 consecutive days. 1 = no change; 2 = double; 0.5 = half | Positive: The number of heat waves can aggravate the detrimental effects of high temperatures, offering minimal relief from heat stress. | 1, 2 |
| **Potential cold stress** | | | | |
| Change in the number of cold days | Days/ year | Change in the number of cold days between 1971-2000 and 2021-2050 when the daily mean temperature is below the 1st percentile of the observed 1971-2000 daily mean temperatures. | Positive: As the number of cold days (relative to the normal local range) increases, elderly people become more susceptible to cold-related morbidity/mortality. | 1, 2 |
| Change in number of cold spell days | Days/ year | Change in the number of days per year contributing to cold spells between 1971-2000 and 2021-2050. A cold spell is defined as a period when the daily mean temperature is below the 1st percentile of the 1971-2000 daily minimum temperatures (locally defined) for at least six consecutive days.. | Positive: The duration of a cold spell can prolong and aggravate the detrimental effects of low temperatures, increasing the risk of morbidity and mortality. | 1, 2 |
| **Potential icy conditions** | | | | |
| Change in the number of freezing point days | Days/ year | Change in the number of days when daily minimum temperature $< 0°C <$ daily maximum temperature | Positive: Temperatures fluctuating around 0°C may lead to icy conditions, which can be hazardous for elderly people | 1, 2 |
| **Elderly Population** | | | | |
| Present-day population | % | Elderly persons (defined locally: age $\geq$ 65 years in Finland and Sweden; $\geq$ 67 years in Norway) as a percentage of the total present-day population | Positive: The greater the proportion of the elderly, the higher the exposure | 3 |
| Future population, 2030 | % | Elderly persons (defined locally: age $\geq$ 65 years in Finland and Sweden; $\geq$ 67 years in Norway) as a percentage of the total population projected for 2030 | Positive: The greater the proportion of the elderly, the higher the exposure | 4, 5 |

1 Observed climate - European 15 minute gridded daily dataset (E-OBS dataset version 3 Haylock et al., 2008)
2 Climate projections - ENSEMBLES project regional climate model dataset (Christensen et al., 2009) and probabilistic projections (Harris et al., 2010); general circulation model (GCM) projections for Finland (Jylhä et al., 2009)
3 Statistics Finland – data for 2009; Statistics Norway – data for 2008; Statistics Sweden data for 2008
4 National Institute for Health and Welfare (Finland), 2009; Statistics Norway, 2006; National Board of Health and Welfare (Sweden), 2008
5 Probabilistic projections for 2040 (Finland – Terämä et al., In preparation)

**Table 3 Indicators of adaptive capacity for characterising vulnerability of the elderly to climate change**

| Indicator | Units | Description | Effect on adaptive capacity | Source |
| --- | --- | --- | --- | --- |
| **Economic** | | | | |
| Elderly welfare recipients (present-day) | % | Proportion of the elderly receiving welfare payments | Negative: A high number of elderly persons receiving welfare payments indicates a high dependence on the state. | 1, 4 |
| **Social** | | | | |
| Elderly living alone (present-day) | % | Proportion of the total population that is elderly and living alone | Negative: People living alone are likely to be less able to cope with the consequences of extreme weather and climate and may be more difficult to alert or to access in emergency situations. | 2, 4 |
| Health care personnel (present-day) | per 10000 | Number of health care personnel: Finland (health care personnel per 10000 inhabitants by sub-region); Norway (labour years for public sector doctors per 10000 inhabitants); Sweden (working public doctors per 100000 inhabitants by county) | Positive: The greater the number of health professionals available to care for the elderly the lower the risk of delayed or impaired healthcare. | 3, 4 |
| Home health care (present-day) | % | Number of recipients of home health services. Finland (elderly in %); Norway (per 1000 persons); Sweden (elderly per 1000 inhabitants) | Negative: The greater the number, the more persons are dependent on State or private assistance. | 3, 4 |

1 Source: Statistics Finland – data for 2008; Statistics Norway – data for 2008; Statistics Sweden – data for 2008; values standardised across all three countries
2 Statistics Finland – data for 2009; Statistics Norway – data for 2009; Statistics Sweden – data for 2008
3 National Institute for Health and Welfare (Finland) – data for 2007; Statistics Norway – data for 2006; National Board of Health and Welfare (Sweden) – data for 2008; values standardised across all three countries
4 Projections for 2040 (Finland only) based on extrapolation of historical time series (Terämä et al., In preparation)

Refinements have been made to the data and to their sources for some of these indicators (primarily for Finland) in the MAVERIC and MEDIATION projects. These are described in section 2.3.3, below.

### 2.3.2 Web-based vulnerability mapping tool (Step 3)

The tool developed for mapping vulnerability indicators was conceived with the following aims in mind:

- to be accessible publicly through the internet
- to store geographically referenced administrative boundaries and information for the different indicators listed in Table 2Table 3 in an online database
- to display information accessed from the database as maps across the three Nordic countries at administrative scales ranging from national to municipal, along with various zoom, pan and point interrogation features
- to provide an interface that allows users to select from the available indicators listed and map these individually, in their original measurement units, across the Nordic region
- to offer options for users to select, weight and combine indicators into composite indices of exposure/sensitivity or adaptive capacity, which can also be mapped
- to facilitate parallel display of exposure and adaptive capacity indicators and indices
- to compute a vulnerability index that is produced automatically from any combination of user-selected exposure and adaptive capacity indicators and/or indices
- to provide clear yet comprehensive supporting documentation explaining the functions of the tool, via clickable information and help buttons

Most present-day and some future demographic and socio-economic statistics were obtained by municipality. Some data were available only for coarser-scale regions. The climate data for the exposure indicators were generated on a regular grid. Values for municipalities were obtained by averaging the grid cell values that cover a municipality's area. In order to combine several indicators into composite indices of exposure (E') and adaptive capacity (A*), it is necessary to adjust them to standard units through a normalisation procedure. This involves linearly scaling values for each municipality relative to the municipality range, where the minimum value is assigned a value of 0 and the maximum a value of 1. Composite indices are produced by averaging the normalised values. These computations are carried out automatically, as soon as multiple indicators have been selected. Note that some indicators are listed as alternatives for representing a single risk factor. For example, in Table 2 three indicators of potential heat stress are listed, but only one can beselected at a time, to avoid over-representing heat stress in a situation where multiple stresses are being combined in a composite index (e.g. of heat stress, cold stress and icy conditions).

Vulnerability indices can be depicted as a combination of normalised E' and A* indicators. High values of E' contribute to high relative vulnerability. In contrast, high values of A* reduce the level of relative vulnerability. A vulnerability index (V) can then be calculated as an exact formulation of the function in equation 5 (Appendix 1):

$$V = [E' + (1 - A^*)] / 2 \qquad (5b)$$

On the mapping tool, once values have been specified and mapped for E' and A* in adjacent panels, values are computed according to equation 5b and mapped automatically on a third panel alongside the other two (see Figure 2).

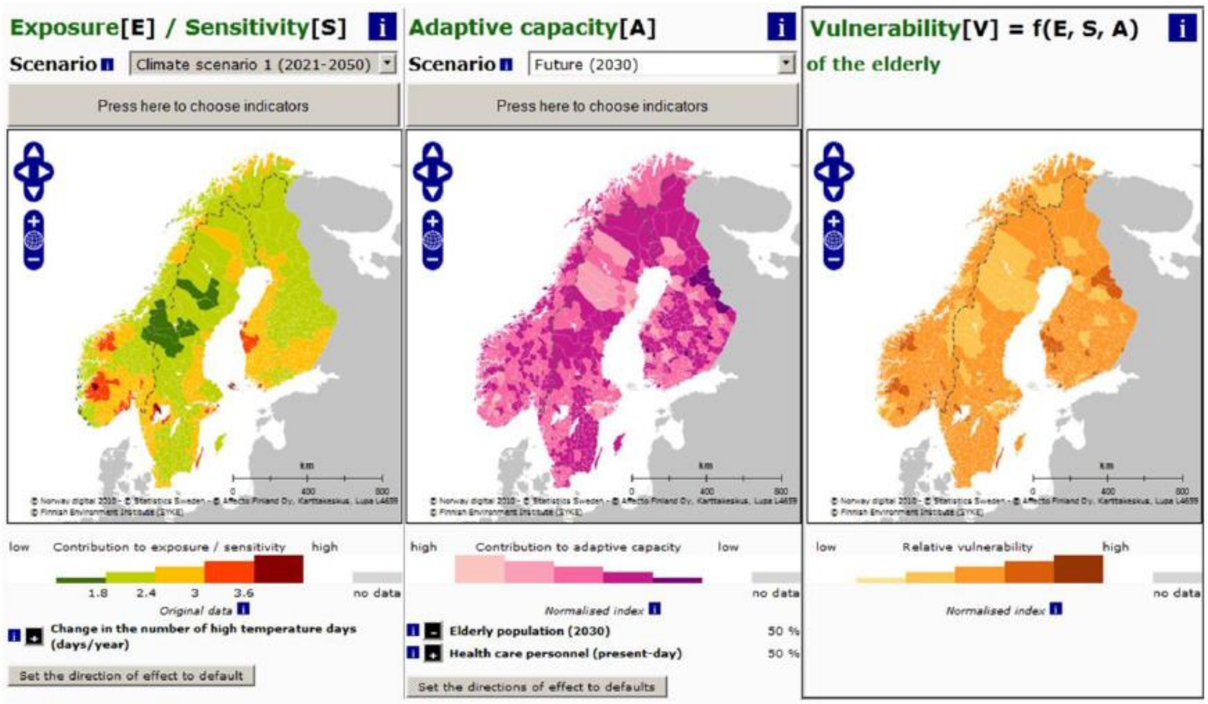


**Figure 2 Screen shot of prototype CARAVAN mapping tool (http://www.iav-mapping.net/CARAVAN) showing an exposure indicator (change in the number of high temperature days) in original units (left panel), a composite adaptive capacity index, combining equally weighted (50%) indicators of future elderly population and present-day health care personnel scaled in relative units (middle panel), and an automatically generated composite of the two into a vulnerability index (right panel). + and – symbols indicate the direction of effect of indicators on their respective composite indices (cf. Error! Reference source not found. Error! Reference source not found.). Note that some aspects of the mapping tool have subsequently been revised in the MEDIATION project.**

### 2.3.3 Projecting future vulnerability

The prototype CARAVAN tool included projections for only a subset of indicators (climate-based and population) and for each of these only a single projection was offered. Adaptive capacity indicators were provided only based on present-day statistics. Two aspects of future vulnerability were explored during revision of the tool (step 5, Figure 1):

*Scenarios of adaptive capacity*

Upper and lower bounds on plausible future trends in the adaptive capacity indicators were defined for Finland, based on extrapolations of historical time series over aggregated regions  (Terämä et al., In preparation). These were selected to provide options for exploring the sensitivity of vulnerability indices to different assumptions about future adaptive capacity and to compare with using present-day values (the trend terms in equation 8, Appendix 1)..

*Uncertainties in projections*

Uncertainty ranges were specified for the exposure indicators, making use of probabilistic projections of both climate and population. For climate, this involved multiple adjustments of observed daily temperatures, sampling across a range of model-derived probabilistically generated projections for the Nordic region assuming the SRES A1B emissions scenario (Harris et al., 2010). In addition, a sampling was undertaken of general circulation model (GCM) projections over Finland, ranging from low-end (5 percentile) warming under the SRES B1 low emissions scenario (surrogate for an aggressive mitigation scenario), to a high-end (95 percentile) A2 high emissions scenario (Jylhä et al., 2009). This allows users to explore how climate change mitigation might contribute to reducing vulnerability (equation 8, Appendix 1). All revised climate projections are for 2020-2049 relative to 1971-2000.

Population projections, like climate projections, are also subject to large uncertainties. Here probabilistic population projections for Finland were generated using the Program for Error Propagation (Alho and Spencer, 1985), focusing on the two largest sources of error in population forecasting: mortality and migration. Projections extend out to 2040, and are for NUTS-2 administrative regions of Finland. More details are presented in Terämä et al. (In preparation).

**2.4 Stakeholder engagement (Step 4)**

The key stakeholders being targeted in this study are national and regional officials responsible for the care and welfare of the elderly, including representatives of social and health ministries, national health and welfare research institutes, umbrella bodies for various associations concerned with the welfare of the elderly, rescue and emergency services and organisations concerned with the planning and design of physical infrastructure for the elderly.

As mentioned above, two approaches were employed for engaging stakeholders: interviews and a workshop.

**2.4.1 Interviews**

Interviews were conducted with a number of public officials. For this, a set of questions was agreed among the Nordic partners. These included questions on:

- Awareness about the vulnerability of elderly people (their constituents) to the effects of temperature and other weather-related challenges
- Knowledge and access to information about climate change
- Opinions on the importance of climate change for public health
- Understanding of climate adaptation and related measures
- Knowledge about regional differences in access to health care among the elderly
- Opinions on public health priorities for the elderly
- Concerns, if any, about consequences of climate change for the elderly Interviews were undertaken in Finland and Sweden during 2010. No interviews could be arranged in Norway, due to a low priority attached to the issue by the experts approached.

**2.4.2 Workshop**

A half-day stakeholder workshop was organised in November 2010 at Stockholm University to explore aspects of vulnerability to climate change among the elderly. It brought together CARAVAN and

MEDIATION researchers projects and Nordic representatives of national and regional organisations who have responsibility for the care of the elderly. The two main objectives of the workshop were to stimulate a discussion of climate change vulnerability of the elderly in the Nordic region between researchers, care providers and local decision makers and to present the prototype web tool, soliciting feedback on how it might be refined or extended to enhance its usefulness for different potential users.

### 2.5 Mortality model (Step 5)

An alternative to an indicator approach to vulnerability assessment is impact modelling (see Appendix 1), and mortality is a definitive impact with a well-established historical relationship to extreme temperature, especially among the elderly population (e.g. Keatinge et al., 2000). Regression models for Finland have been developed relating mortality statistics for hospital districts to regionally-averaged daily temperatures over the period 1971-2010. A log-mortality-temperature relationship was defined by estimating the optimum temperature at which the lowest seasonal mortality is observed (base mortality, Tb). Mortality increases at temperatures above Tb (heat effect, slope a) and below Tb (cold effect, slope b). Three sets of model parameters were calibrated: using data from across the country (all Finland), and separating southern and northern regions (Table 4). Note that mortality statistics were for the whole population, though it is known that a large majority of temperature-related deaths, especially under extreme temperature conditions, are observed among the elderly.

These models were next used to predict mortality for observed daily temperatures adjusted according to different future projections. Estimates of mortality rates were then converted to absolute mortality by using population statistics for each municipality.

**Table 4 Parameters for models calibrated with data from all Finland and separating southern and northern hospital districts for the period 1971-2010. Source: Matti Lahtinen, Finnish Meteorological Institute.**

| | All Finland | South | North |
|---|---|---|---|
| $T_b$ (°C) | 11.1 | 11.5 | 11.2 |
| $a$ (slope above $Tb$) | 0.011447 ±0.01209712 | 0.006723 ±0.01 | 0.03015 ±0.025 |
| $b$ (slope below $Tb$) | -0.0048201 ±.00186494 | 0.007846 ±0.002 | -0.006006 ±0.00318892 |
| log(base mortality) | 0.88 | 0.92 | 0.83 |

## 3 Results

### 3.1 Feedback on the mapping tool (Step 4)

The online mapping tool is designed to raise awareness of current and prospective climate change related risks to the elderly. As such, and within the constraints of the background data and functionality of the tool, mapped outcomes are determined by the user rather than by researchers. As such, no specific results are reported here. Instead, the outcomes of the study are discussed in light of feedback and suggestions obtained at the Stockholm workshop.

All workshop participants were invited to provide feedback on the usefulness and usability of the prototype mapping tool. The tool was regarded as a visually attractive, colourful and useful device for raising awareness of climate change vulnerability. In general, maps were seen as a good way of communicating aspects of climate change vulnerability to planners, who are accustomed to reading maps and use them in their everyday work. Most of the selected indicators were regarded as useful for describing some issues of vulnerability.

It was observed that the proportion of elderly receiving home health care is more likely to increase adaptive capacity the higher the value, rather than decrease it (in contrast to the default assumption – Table 3). This is based on the assumption that municipalities with a better economic situation can more easily offer home health care services to their citizens while poorer municipalities have stricter requirements for deciding who is entitled to home health care. Thus, receipt of home health care is not necessarily directly related to the condition of an elderly person. This ambiguity in the direction of effect of certain indicators on vulnerability is already addressed through an option to reverse the direction of effect from a default case.

The intended target group of the mapping tool was unclear to some participants, and it was suggested that this should be clarified. The municipality-scale information that is provided on the mapping tool was thought to be useful on national to regional scales. Planners of cities or municipalities, however, would require more spatial detail for their decisions. Some ideas were exchanged on how pockets of high vulnerability might be recorded on maps that currently show only municipality-level indicators. It was suggested that options for selecting information for individual cities might be an interesting addition to the tool. This was not followed up in Step 5, although there might be scope for such detailed analysis in further work.

Other suggestions for enhancing the tool, some of which have been acted upon subsequently, included:

- providing examples of how the maps could be used to inform the planning of adaptation measures and what kind of adaptation issues might be addressed with the data provided by the tool (implemented in Step 5)
- including information on adaptation options relevant to the vulnerabilities being mapped (implemented in Step 5)
- indicating the locations and distributions of various key stakeholder organisations that could be contacted for possible follow-up actions
- mentioning the limitations of the data presented, in order to avoid too strict interpretation of the results (a front page disclaimer was added in Step 5)
- putting in place a means for updating indicator data in the future (updating was an integral part of the revisions in Step 5)

### 3.2 Interview results

Several factors were identified by interviewees in Finland and Sweden as increasing the vulnerability of the elderly. Those elderly persons suffering from conditions such as as cardiovascular and respiratory illnesses, weakening of cognitive abilities or depression as well as those experiencing a poor economic situation, living alone and with few social contacts were seen as especially vulnerable to the impacts of climate change.

Some of the key findings distilled from the sample interviews included:

- A general awareness of the threats that heat-waves pose for elderly people

- Recognition of increasing risks of storms, extreme snowfall and power cuts and their effects, especially in rural areas
- The injury risk of slippery streets was not as clearly connected with climate change and was seen more as a question of street maintenance by respondents in Finland, though accidents involving falling among the elderly was recognised in a climate change context by interviewees in Sweden
- Climate change impacts had not been taken into account systematically at a planning and strategic level in the interviewees' organisations.

Some future developments within elderly care that can have interactions with climate change were recognised. The dependency ratio between numbers of elderly and people of working age is changing and there will be fewer people available to take care of a growing number of elderly in the future. A larger share of the elderly is also expected to be living at home (this is government policy in most Nordic countries), which can increase their vulnerability to heatwaves and other weather events. It was also mentioned that there is a risk of growing polarisation in care provision among the elderly population as well as a widening gulf between municipalities.

Examples of potential adaptation measures that were brought up by the interviewees include:

- Raising awareness of extreme weather events and their impacts on the elderly
- Promotion of a social, healthy and active lifestyle for all (public health)
- A more communal way of living
- Introducing "social janitors" in blocks of flats
- Planning of future urban environments to account for the needs of the elderly

Some of these measures have been included as supporting information in a revised version of the web tool.

**3.3 Projected mortality**

The mortality models described in section 2.5 were used to estimate regional mortality rates across Finland under present-day observed (1971-2000) and future projected (2020-2049) climates. Observational daily temperature data were available for a regular 10 km grid over Finland (Jylhä et al., 2009). These were then adjusted to represent a range of uncertainties in GCM projections for 2020-2049 (see section 2.3.3, above). The models were run over the grid, mortality rates computed and then averaged by municipality. Results for the present-day climate and median A1B scenario are shown in Figure 1, assuming mortality parameters for all Finland (cf. Table 4). Absolute mortality estimates were also computed, by using population statistics for each municipality (observed and projected). Absolute mortality in the year modelled as recording the maximum mortality of a given period is also shown in Figure 3. Estimates for the whole country and for Helsinki, using all three mortality models, are depicted in Table 5.

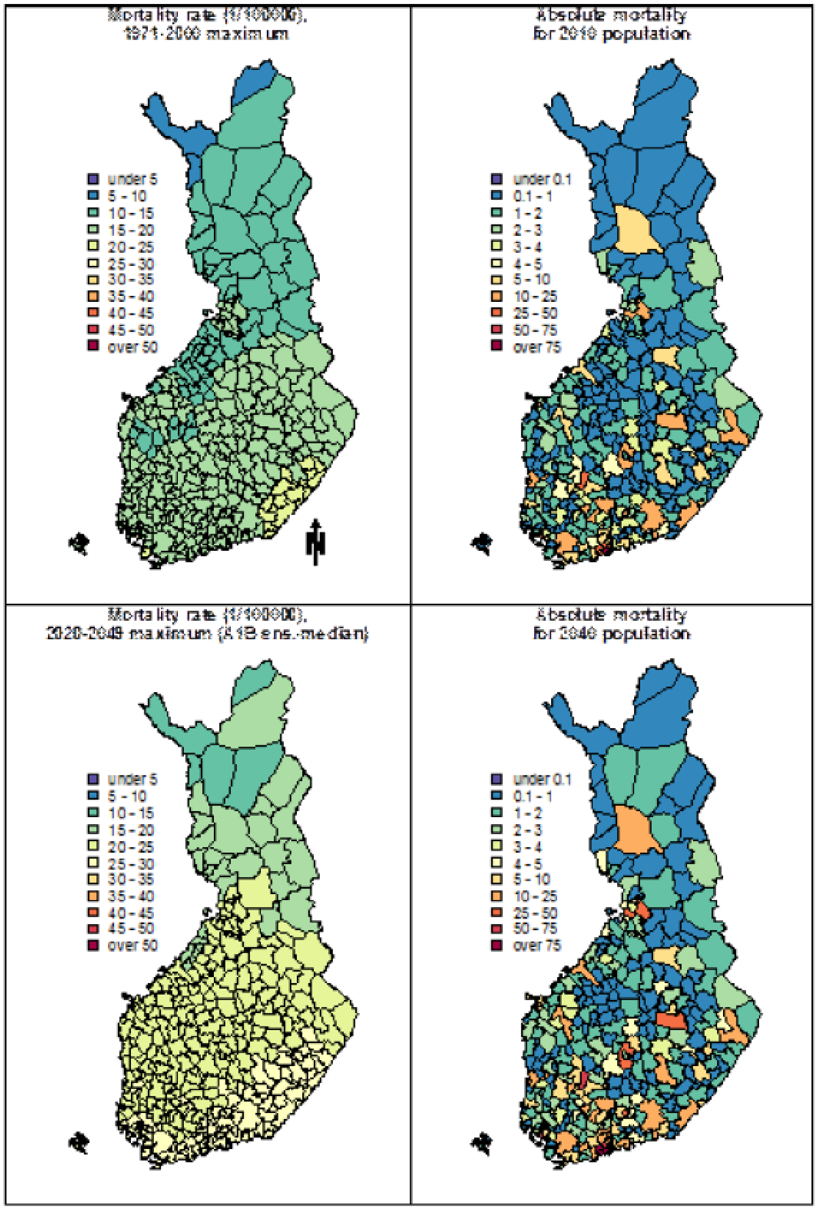


**Figure 3 Estimated mortality rates (per 100000 persons – left panels) and absolute maximum number of annual deaths (right panels) during the periods 1971-2000 (top) and 2020-2049 (bottom). Projected climate is based on a 19-GCM ensemble median for an SRES A1B emission scenario; constant parameter values are assumed for the whole country.**

**Table 5** Estimated present-day and future annual heat-related deaths in Finland (Helsinki in parentheses) for three alternative spatial extrapolation methods (constant parameter values in northern and southern Finland, linearly interpolated between the regions and constant for the whole country). Mortality estimates for each period are shown for the year with the maximum rate, and for the 30-year average rate

| | Regional specification of model parameters | | |
|---|---|---|---|
| **Time period** | **N. Finland / S. Finland** | **Linearly interpolated** | **All Finland** |
| **1971-2000 climate, 2010 population:** | | | |
| Total population | | 5375276 (588549) | |
| Maximum annual mortality | 719.3 (63.4) | 978.0 (63.3) | 951.1 (113.2) |
| 30-year mean mortality | 460.9 (42.4) | 625.2 (42.4) | 643.0 (77.6) |
| **2020-2049 climate, 2040 population:** | | | |
| Total population | | 5984898 (727605) | |
| Maximum annual mortality | 1130.5 (108.9) | 1512.0 (108.8) | 1490.9 (194.4) |
| 30-year mean mortality | 824.9 (83.3) | 1101.8 (83.2) | 1128.6 (149.8) |

## 4 Discussion

This paper has detailed recent and ongoing research aiming to draw attention to the risks of climate change for the elderly population in the Nordic region and the possible need for adaptation responses. To date, the study has followed five analytical steps (Figure 1), with a research question posed at each step, and allowing for iteration to refine, reconsider or complement previous steps according to feedback from stakeholders and emerging research questions.

A key outcome of the research is the development of an interactive web-based tool for mapping and combining indicators of climate change vulnerability of the elderly, by municipality, across the three Nordic countries: Finland, Norway and Sweden. The tool can also be used for projecting temperature-related mortality in Finland under different projections of future climate, and for depicting background information on potential measures for adapting to more frequent and severe heat waves.

The value of a prototype version of the tool as an awareness raising device was confirmed at a stakeholder workshop, though modifications and extensions were also proposed by care providers and other persons concerned with the well being of the elderly. Some of these suggestions have been implemented in an updated version of the tool prepared during Step 5 of the study.

Of the many insights obtained from this research, five are highlighted in the following sub-sections.

### 4.1 A shift in the onus of analysis and interpretation

In spite of the normative aspects of indicator analysis and mapping, heavily critiqued in earlier reviews (see section 1.4), the stakeholders consulted in this work responded positively to the opportunities presented by the tool for visualising regional variations in certain key indicators of potential vulnerability. Some of these indicators, such as weather extremes, are not commonly available at municipality scale. Moreover, this is a first attempt to bring together exposure and adaptive capacity indicators relating to climate change vulnerability of the elderly across the region. The tool is fully interactive, indicators are clearly documented and can be presented in their original measurement units and, most importantly perhaps, it is users rather than researchers (as in most previous studies) who determine the indicators and indices selected and mapped.

### 4.2 Perceptions of vulnerability.

The indicators of adaptive capacity selected for this study all reflect tangible attributes, such as economic resources, social provision and accessibility. However, these indicate only the potential material capacity of populations to adapt to a changing climate, and this may not reflect the reality of adaptive behaviour. This paper has suggested how potential adaptation (adaptive capacity) might be translated, analytically, into actual adaptation (see Appendix 1).

However, mediating this translation, the uptake of adaptation is strongly affected by individuals' perceptions of their vulnerability to climate change. These are characteristics are highly subjective and difficult to measure. A useful illustration of this is a study of Norwegian elderly living in Spain (Ruud, 2010). Here, respondents to an interview survey did not necessarily perceive themselves either as vulnerable to heat waves or as being elderly, even if according to objective measures they might be regarded as both. Though they are objectively more at risk of adverse effects in the warmer Spanish climate than in Norway, unless they had actually experienced the ill-effects of heat stress many were unaware or sceptical of such impacts.

### 4.3 Limitations of the mapping tool.

The mapping tool presents information at the scale of municipalities, which is helpful for comparison at regional, national and trans-national scales, but is of limited use for stakeholders working at municipal scale, who would require finer-scale mapping of relative vulnerability in order to target adaptation. Such mapping might be feasible in a follow-up study, especially in urban centres with more detailed statistical data on demographic and socio-economic indicators. The variables chosen as indicators were also limited to those for which data were available across all three Nordic countries, though the number could be expanded for any individual country. New common indicators could also be added in future – for example, one indicator of the general health of the population, and its likely sensitivity to weather effects for any particular age cohort, could be life expectancy.

### 4.4 Specifying future conditions.

The future predisposition of the elderly to climate change will be conditioned as much by ongoing socio-economic trends as by changes in the physical hazard (see equation 8, Appendix 1).

The challenge of projecting socio-economic conditions over multi-decadal time horizons into the future may have deterred many analysts in the past from incorporating such scenarios in vulnerability indices along side projections of future climate. However, there can be value in exploring the relative sensitivity of vulnerability indices to plausible future trends in different socio-economic indicators, and an attempt is made in this study to specify upper and lower bounds on the extrapolation of historical time series. The uncertainties surrounding all projections merit close attention, and many of the revisions of the tool focused on representing these by way of alternative scenarios as well as probabilistic projections. Future elaborations might take in regional manifestations of a new set of shared socio-economic pathways (SSPs) being developed to supersede the SRES scenarios (Moss et al., 2010; O'Neill et al., submitted).

### 4.5 Modelling mortality and other impacts

One of the new avenues pursued in Step 5 of the study was work to develop impact models relating temperature to mortality in Finland (paralleling similar modelling work conducted during the past decade in Sweden, e.g. Rocklöv and Forsberg, 2008, 2009) and using these to project regional variations in Finnish mortality. Definitive rather than indicative estimates of impacts, such as mortality and morbidity, whether for the elderly or for the population as a whole, raise the prospect of being able to evaluate the potential economic and social costs to society of climate change impacts on human health, building on earlier work in Europe (e.g. Watkiss et al., 2010).

**List of symbols**

A: Slope of mortality curve above base temperature (heat effect)
A: Adaptation
A*: Adaptive capacity
B: Slope of mortality curve below base temperature (cold effect)
ΔC: Change in climate
E: Exposure
E': Exposure (including sensitivity)
I: Impact
M: Mitigation
RF: Response (future)
RP: Response (present-day)
S: Sensitivity
T: Trend
Tb: Base temperature for mortality
U: Location parameter
V: Vulnerability

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**Appendix 1: Reconciling impact and vulnerability approaches**

The impact of future climate change on a system or process ($I$) can be described as the difference between the response of the system in some future period ($R_F$) under changed climate (average and/or variability) and the response in a reference period at the present-day ($R_P$):

$I = R_F – R_P = \Delta R$ (1)

A future impact can also be expressed as a function of exposure ($E$) of the system or process to a change in climate and its sensitivity to that change ($S$):

$I = f(E, S)$ (2)

This term is sometimes referred to as potential impact (Metzger et al., 2008), as it excludes explicit recognition that the exposure and sensitivity terms (and hence the impact) could be expected to be modified as climate changed (e.g., through adaptation). Impact responses are commonly estimated using formal mathematical models, where causal relationships are represented in a system of equations. However, where such causal models do not exist, more descriptive models, such as indices, may also be applied.

Exposure is a function of the magnitude of climate change ($\Delta C$) – which can refer to climatic as well as associated variables such as atmospheric composition or sea level – and the location or circumstances of the system or process with respect to the climate change ($u$):

$E = f(\Delta C, u)$ (3)

Sensitivity refers to the impact response per unit climate change moderated by a given circumstance:

$S = I / \Delta C_u$ (4)

Exposure and sensitivity are crucial terms for considering adaptation (see below).

The definition of vulnerability to climate change ($V$) commonly applied for developing indices is given by IPCC (2007) as a function of exposure, sensitivity and adaptive capacity ($A_*$) of the system or process:

$V = f(E, S, A_*)$ (5)

It is apparent that this formulation is an extension of (2), where the introduction of adaptive capacity is a way of bridging between future impact and vulnerability. Both vulnerability and adaptive capacity refer to potential rather than realised outcomes (in the absence of data to describe these and/or causal models to relate them). Vulnerability is an estimate of the propensity to be adversely impacted (IPCC, 2012) rather than an estimate of actual impact to be expected. Similarly, adaptive capacity describes the potential for adaptation based on the resources available, rather than the actual readiness and ability to adapt. Note also that vulnerability alludes to detrimental impacts, whereas some impacts may in fact be beneficial.

In order to progress from vulnerability shown in (5) towards realised impacts requires that the exposure and sensitivity terms in (2) be modified.

For exposure (3), the climate change term can be altered through mitigation ($\Delta C_M$). The circumstances in which the climate change is experienced ($u$) can also be modified. There are two ways that this might happen: (i) through general socioeconomic trends ($T_u$) that continually alter the circumstances of populations or systems (e.g., demographic change, urbanisation, land use change), and (ii) by adaptation ($A_u$) that aims to alter circumstances to provide benefits with respect to climate change (e.g., building dykes, planning green spaces, or altering forestry rotation times):

$u = f\,(T_u, A_u)$ (6)

Sensitivity (4) can also be altered in two ways: (i) through general socioeconomic trends ($T_S$) that may alter the intrinsic sensitivity of a system exposed to climate change (e.g., people are less physiologically sensitive today to extreme temperatures than people of the same age in previous decades, due to general enhancements in health and overall life expectancy), and (ii) by adaptation ($A_S$) that targets intrinsic properties of a system's sensitivity to climate (e.g., through technological means like breeding for high temperature or drought tolerance in plants, or through social measures such as awareness raising or emergency preparedness):

$S = f\,(T_S, A_S)$ (7)

By inserting expressions (6) and (7) into (2), the adaptive capacity term in (5) is operationalized into concrete adaptation measures:

$I = f\,(\Delta C_M, T_u, A_u, T_S, A_S)$ (8)

where future impacts are a function of the climate change (mitigated to a greater or lesser extent) mediated by future trends and targeted adaptations that modify both circumstantial exposure and intrinsic sensitivity. These formulations are illustrated in Figure 4.

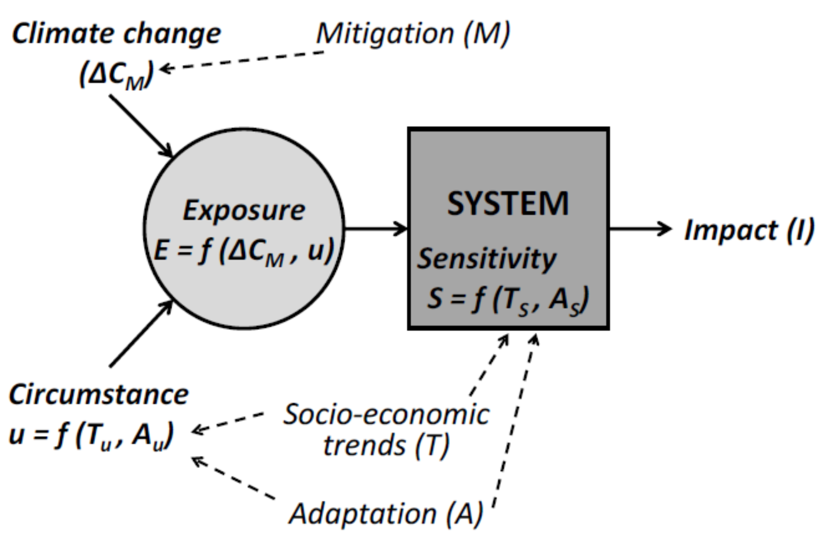


**Figure 4 The impact of climate change on a system as a function of exposure and sensitivity (schematic)**

It is interesting to reflect that while the large majority of index-based vulnerability studies address the changing climate using future scenarios, very few use scenarios to specify the four other terms, instead fixing them at present-day reference levels. In other words, vulnerability to a changed climate is commonly being assessed assuming no future change in circumstances, sensitivity or adaptive capability (and see Preston et al., 2011). Notable exceptions include work on ecosystem service vulnerability (Acosta et al., 2013; Schröter et al., 2005) and coastal zone vulnerability (Nicholls et al., 2008).

## The Rhine River case

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**Introduction; thresholds in Rhine river policies**

How to put results of climate impact assessments on political agenda's so that the right level of attention is raised? There is a growing tendency in science to identify and communicate thresholds and tipping points in physical and in social systems forced by climate change (Werners et al. 2013). Lenton et al. (2008:730) identify potential tipping points in earth's system (like the Arctic sea-ice and the Greenland ice sheet) and express the hope that communication of these threats will influence climate policy (Lenton et al. 2008. P. 1792). In their analysis of the use of climate tipping points and thresholds - both in scientific and in public discourse- Russill and Nyssa (2009) recognize the use of the terms as a means to raise alarm and to attract political attention (Russill and Nyssa 2009). They warn however for unexpected and unwanted effects of such communications (increasing political apathy for instance) and recommend to be more clear and explicit on what is exactly communicated.

In the Netherlands researchers use tipping point analysis to inform planning of adaptation strategies (Walker et al. 2013). Kwadijk et al. (2010) define an adaptation tipping point as the moment when the extent of the impacts of climate change is such that "*the current management strategy will no longer be able to meet the objectives*" (Kwadijk et al. 2010:730). The identification of future climate induced policy failure will communicate the urgency (or the lack of urgency) of adaptive action and forms a basis for assessments of priority in actions. Werners et al. (2012) use a broader definition of threshold to include social preferences, stakes and interests. An adaptation turning point is defined as: "*a moment when a socio-political threshold is reached, due to climate change induced changes in the biophysical system*"(Werners et al. 2012:3).

Both approaches assume a future change in a management regime forced by impacts of climate change. The understanding of the management regime however differs. Kwadijk et al. (2010) predominantly focus on formal policies, often institutionalized in legal standards, while Werners et al. (2012) takes a broader open governance approach to management regimes and uses turning points to indicate that policy thresholds are not crossed at once, but go through a period of reframing and discussion, before the regime shifts toward a new state (Werners et al. 2012).

This case study applies the adaptation tipping or turning point approach in the Rhine river basin. Since climate change became an issue, the potential impacts on the Rhine hydrological regime have been subject of study of several research projects and scientific publications (see Middelkoop et al. 2001; Middelkoop and Kwadijk 2001; Barnett et al. 2005; Te Linde 2006; Görgen et al. 2010; van Pelt and Swart 2011; Te Linde et al. 2012). Most of this research was directed at floods and as a result adaptation strategies for flood security infrastructure are being developed. However, the need to anticipate with changes in low flow events has received insufficient attention.

The aim of this paper is two-fold: the first is to identify thresholds in water management regimes forced by projected increases in frequencies of extreme low flow events and possible adaptation options in the Rhine river. We claim that finding thresholds in water management regimes will allow us to assess the urgency for managers to take decisions on adaptive action. In defining a threshold we will adopt the definition proposed by Russill and Nyssa (2009): a threshold is *"a shift from one identifiable regime to another at an identifiable point without entailing rapid change"* (Russill and Nyssa 2009:343). The 'identifiable regime' in this case study is a river management regime which aims at making use of river water for the purpose of a sector or a policy process.

The second objective of this paper is to reflect on the application of the adaptation tipping or turning point approach and the use of associated tools and methods. In applying this approach, we follow the decision pathways provided by the MEDIATION Adaptation Task Navigator (ATN). The ATN is a decision support framework designed to assist policymakers on selecting methods in adaptation (www.@@ to be defined yet).

As the Rhine river basin covers eight countries, transboundary policies are coordinated in two international commissions. The first is the Central Commission for Navigation on the Rhine, founded in 1816 to regulate conditions for inland shipping. The second is the International Commission for the Protection of the Rhine, founded in 1963 with the aim to improve the environmental and ecological qualities of the river. Two management regimes, both connected to the international commissions mentioned above, will be assessed: inland waterway transport, and the reintroduction of the salmon as icon for ecological restoration of the river.

The following questions are addressed:

1. When will thresholds in governance of inland shipping and salmon reintroduction be crossed under pressure of changing low flow conditions?
2. What options do water user governance systems have to avoid threshold crossing?
3. What are assumptions and methods used in the threshold assessment approach?

**Water user concerns about lack of water**

Starting in the 18th century, the river hydro-morphological structure was drastically re-engineered through canalisation and normalisation works and construction of dams in order to adapt the river to the needs of its water users (Cioc 2002). Since the 70th of last century the ecological importance of the river came back on the policy agenda and since then much is invested in ecological restoration (ICPR 2009). Currently, about 58 million people live within the Rhine catchment area and the economies of the riparian countries depend on the river for: inland shipping, drinking and industrial processing water, irrigation for agriculture, hydro-power, discharge of pollutants and cooling water (ICPR 2009).

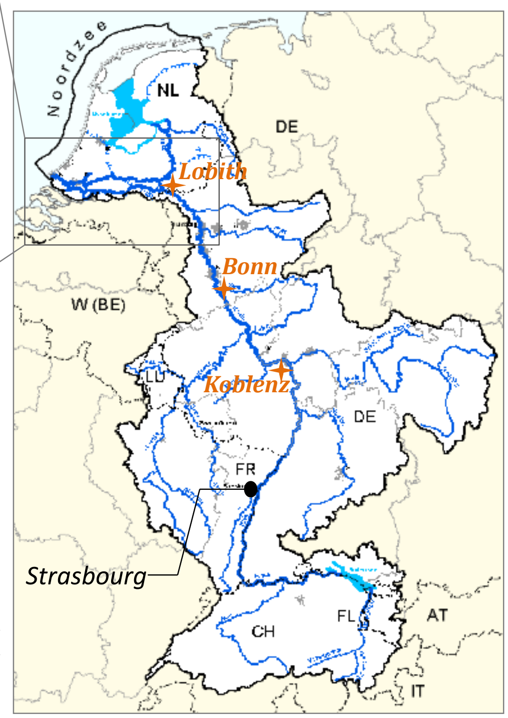
The definition of a low flow may vary depending on the water use at stake. From a statistical point of view, in the Rhine river a flow is considered to be low when it is below the Q5% discharge (Havinga et al. 2006) which is about 1,020 $m^3/s$ at Lobith gauging station. Water users are accustomed to average low flows, and they usually can deal with the damaging impacts of extreme low flows, like in 2003, provided that these do not occur too often. But what if average low flow discharges diminish? And what if the frequency of extreme low flows increases?

As a matter of fact, climate change will lead the Rhine River to become into a predominantly rainfall driven system (Middelkoop and Kwadijk 2001). Higher temperatures will trigger precipitation to fall as rain instead of snow, resulting in lesser snow storage in the Alps during winter. Lower snow storage, together with increased evaporation during summer, will result in lower discharge volumes during summer and autumn (Middelkoop and Kwadijk 2001; Hurkmans et al. 2010).

This case study assesses when, from the perspective of water users, changes become intolerable and water use practices will fail and makes an inventory of adaptation options for water users. We selected two illustrative water use management practices (see Figure 14 for locations):

1. Reintroduction policies of the salmon. The salmon is used as a symbol and an indicator species for the ecological quality of the river, downstream of Basel, Switzerland. We selected this policy to address the large investments made for environmental and ecological restoration (Bölscher et al. submitted).
2. Inland waterway transport. The river is facilitating transport of over 200 million tons of goods annually. We selected this sector because riparian economies depend on it. The region addressed in this study is the river section between Rurh area and the port of Rotterdam, because it is the busiest transport section along the Rhine river (Riquelme-Solar et al. to be submitted).


***Study area navigation case study:*** *the lower Rhine from the Ruhr area to Rotterdam through the Waal River which is the main Dutch branch of the Rhine. Hydrological data used on this study are based on measurements taken at the Lobith gauging station (see figure).*




***Study area salmon reintroduction case study:*** *the Rhine river from Strasbourg. Hydrological data used on this study are based on measurements taken at the Koblenz, Bonn and Lobith gauging stations (see figure).*

**Figure 14.** Rhine River Basin and zoom in to the area addressed on the navigation case study. Source: www.iksr.org

**Analyzing thresholds in water use**

*Analysis steps taken*

Figure 15 presents an overview of the steps taken in this research. Point of departure is the concern of water users about future low discharges in the Rhine as a consequence of climate change. The research questions in this case study are based on these concerns and the objective is to provide river managers with relevant analysis results. Step 1 assesses the impact of climate change on two management regimes. This step corresponds with the first entry point in the Adaptation Task Navigator: “Appraising vulnerability and impacts”. Results from this first step form a basis to ask the next question in step 2. This step corresponds with the second entry point of the Adaptation Task navigator: “Appraising and choosing adaptation options”. This chapter discusses decisions on the use of methods in both steps and presents results of application of these methods.

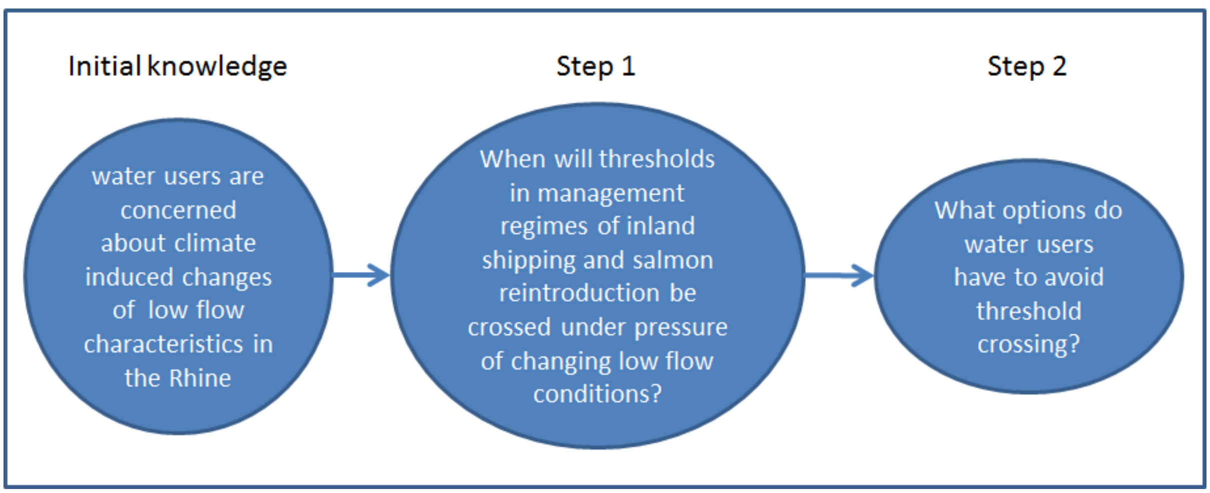



**Figure 15.** Steps taken in this case study

**Step 1; when will thresholds be crossed?**

*Entry point and path through decision trees*

Figure 16 shows the pathway through the impact analysis section of the Adaptation Task Navigator used to select the appropriate research methods.

This case study started with an inventory of existing studies on future impacts on the Rhine hydrological regime. A considerable set of impact studies, both on the Rhine river future hydrology in general (see Middelkoop et al. 2001; van den Hurk et al. 2005; Te Linde 2006; Carambia and Frings 2009; Görgen et al. 2010; Hurkmans et al. 2010) as on climate impacts on sectors (see Moser et al. 2008; Flörke et al.

2011; Klijn et al. 2011; Krekt et al. 2011) was uncovered. Most climate impact studies however take time windows from 25 to 35 years mean values as a basis for comparisons between climate characteristics in the present with periods in the near and distant future. This kind of projections does not allow for the identification of the timing of threshold crossing. Therefore, it was decided to take a step back (see two feedback arrows in bold in Figure 16) and to look for models with transient projections. Such models generate transient time series of daily discharges over the future. This output allows for the identification of low flow periods of a determined length and their frequency over time.

The objective of step 1 is to find thresholds in actual management regimes, which assumes that no changes are made in the future. Therefore we do not include adaptation in the projections (see figure 3).

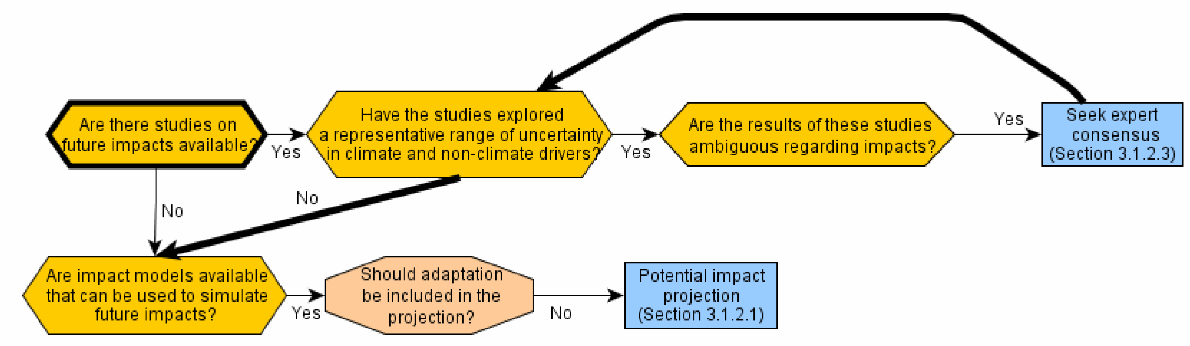



Figure 16. Decision nodes following the impact analysis pathway of the Adaptation Task Navigator

**Method applied**

Following consultations with experts threshold parameters were set. These parameters are expressed in terms of intolerable change in the bio-physical system (e.g. water temperature, water depth, water discharge). Also a critical number of days of intolerable conditions (length and/or frequency of such an event) were defined.

In order to identify thresholds parameters for the salmon reintroduction case, interviews to experts were supplemented with literature review on formal policy objectives and assessment reports (Bölcher et al. 2013). Semi-structured interviews with experts, policy makers and inland shipping companies' were performed to identify thresholds on inland waterway transport (Riquelme-Solar et al. to be submitted).

Table 1: steps taken

| **Step 1 : When will thresholds in management regimes of inland shipping and salmon reintroduction be crossed under pressure of changing low flow conditions?** | | | |
|---|---|---|---|
| | **Objective** | **Question** | **Method** |
| **Sub-Step** | Definition of | At what point low flow conditions | Literature review and interviews to experts and policy makers |

| | | | |
|---|---|---|---|
| **1:** | threshold value | become a threat to the socio-political system of concern? | |
| **Sub-Step 2:** | Definition of threshold time parameters | How long (or with what frequency) can the socio-political system cope with such an event? | Interviews to experts, policy makers and/or practitioners |
| **Sub-Step 3:** | Translating parameters into time scale | When can we expect this threshold be crossed? | Salmon reintroduction: Analysis of one set of hydrological and temperature projections at Koblenz, Bonn and Lobith gauging stations: van Vliet et al. (2012), VIC-RBM hydrological-water temperature model for A2 and B1 SRES scenarios.<br><br>Inland shipping: Analysis of two sets of transient discharge series at Lobith gauging station:<br>a) Hurkmans et al. (2010), Variable Infiltration Capacity (VIC) model for A1B, A2 and B1 SRES scenarios.<br>b) Haasnoot et al. (in prep.), HBV model for G and W+ KNMI'06 scenarios. |

**Results achieved**

***Salmon reintroduction policy***

Since the approval of the Rhine Action Plan in the 1980's, governments of the riparian states as well as regional authorities and environmental NGO's are committed to the achievement of a sustainable salmon population along the Rhine and its tributaries. Extended periods of water temperatures higher than 23°C will put this policy objective at risk since this situation will trigger a significant reduction of up-river salmon migration; however, the exact length (number of days) of those extended periods was not possible to determine. According to the projection analysed for B1 and A2 SRES scenarios, the salmon reintroduction policy will be at risk of failure after 2060 (Bölscher et al. submitted).

***Inland waterway transport***

The Rhine river is one of the most important commercial inland waterways worldwide (Cioc 2002). The fairway between Ruhr and Rotterdam is the busiest river section and maintaining reliable inland shipping service along this stretch results of vital importance from an economic perspective. Water depths in the fairway below 2.1 m trigger insurmountable problems for navigation since ships do not have enough draft available for sailing, even with the lowest freights. When a period of such a low water depth extends for longer than 7 days, production processes of those companies whose inputs are transported by inland shipping are significantly disturbed. According to the projection analysed, this situation will take place at least once per year after the first half of the 2080 decade in the case of the

W+ and A1B scenarios or after the first half of the 90's in case of A2 scenario. The threshold will not be reached according to G and B1 scenarios (Riquelme-Solar et al. to be submitted).

**Reflection on results**

Transient projections of water temperature and discharges show threshold crossings in the second half of this century, but results vary with the scenario used. The results show a risk of threshold crossing, but do not allow to define a specific period.

The challenge of identifying well-defined thresholds in management regimes lies in the nature of the socio-ecological system addressed. Assessing two management regimes shows that identifying thresholds in biological systems like the salmon migration in the Rhine is more difficult than finding thresholds in a system like inland waterway transport. A nature oriented policy like reintroduction of the salmon has to consider ecological uncertainties like the period a salmon population can handle temperatures above 23°C before stopping up-river migration. This period depends on a series of biological variables, and most of these are not known, yet. An infrastructure oriented management regime like inland shipping connects to well-known hard design criteria, like depth standards of ships.

The uncertainties of the results obtained for both cases are also related to the uncertainty on the hydrological and water temperature projections used. There is a cascade of uncertainties attached to any climate projection, starting from the selection of climate scenarios, to the global climate model, the downscaling method, and finally the hydrological or temperature model coupled for translating atmospheric data into stream flow or water temperature responses (van Pelt and Swart 2011). Given these cascades of uncertainties usually a large number of scenarios and models is used to create an ensemble of outcomes, which gives an impression of the level of uncertainty. But , the selection of the sets of projections analysed in both cases was limited by the scarce number of transient projections currently available for the Rhine River Basin. Besides, unlike studies on future high water discharges, research on future low flows is limited. As a result, none of the transient projections analysed were specifically developed for the accurate projection of low water situations.

**Adaptation options**

*Entry point and path through decision trees*

As step 1 resulted in an assessment of threshold crossings and show a risk of such crossings in the second half of next century, step 2 is to consider adaptation options. Figure 17 shows the pathway through the adaptation option section of the Adaptation Task Navigator used to select the appropriate research methods.

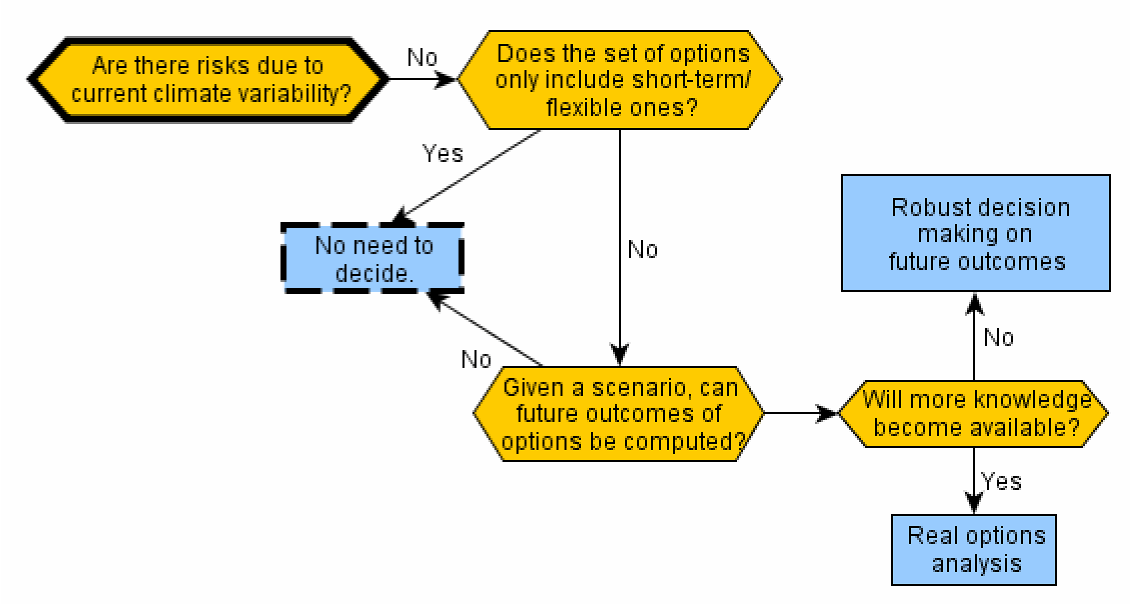



Figure 17. Decision nodes following the adaptation options pathway of the Adaptation Task Navigator.

Table  presents the sequence of questions and answers considered while following the pathway of figure 4.

Table 2. Question and answers decision pathway

| Question | Consideration | Answer |
|---|---|---|
| Are there risks due to current climate variability? | With current climate variability there are no risks of threshold crossing | No |
| Does the set of options only include short-term/flexible ones? | The assessment identified thresholds in the second half of this century and it is reasonable to also consider adaptation options for the long term | No |
| Given a scenario, can | If parameter values of thresholds change impacts can be | Yes |

| | | |
|---|---|---|
| future outcomes of options be computed? | compared with existing model outcomes. If the river basin character changes model parameterisation needs to be adapted and new transient runs must be produced | |
| Will more knowledge become available? | More sophisticated climate – hydrology models will become available, reducing model uncertainties. Developments in sectors will lead to different starting conditions of analyses. | More knowledge will become available. |

*Method applied*

In November 2012 about 60 experts and policy makers from Rhine River Basin countries met for a three day conference in Kleve[15]. The objective was to discuss options for adaptation in extreme low flow events. Results from this conference are used together with literature review (see also Bölscher et al. submitted; Riquelme-Solar et al. to be submitted) and experts consultation to identify alternatives for adaptation in both cases. A large set of potential adaptation measures, was first organized in three management regime categories: 1) integrated management of the river basin, 2) management of reintroduction of the salmon, 3) management of inland shipping conditions. Within these categories adaptation measures were grouped into three strategic options each (see figure 5).

For each strategic option estimates were made of the time needed for implementation. The time needed for implementation depends on the number of necessary policy and planning cycles (4-6 years) before implementation can start. Another consideration is whether land use changes or new infrastructures are needed. Management of water levels in reservoirs for instance are governed by existing gates. If new policies and regulations add mitigation of extreme low discharges as an decision criterion, gate management can change, without extra infrastructures. In the case of canalization construction of weirs and locks is required on top of time needed for decisions.

Estimates of the potential delay of threshold crossing in this case study is based on expert judgments. Two categories of delays were used: 1) delay of threshold crossing of one to several decades, 2) delay of threshold crossing for longer periods. This very rough distinction can be refined by including adaptation options in model schematizations and re-run the threshold assessments as described in the first step of this case study  (see Haasnoot et al. 2013 for examples). This case study restricted itself to an analysis based on the described distinction in two classes.

*Results achieved*

Figure 5 presents 9 strategic adaptation options with estimations of implementation times and potential delays of threshold crossing. Options 1, 4 and 7 are 'do nothing' options. Without adaptive action the management regime will have to transform its objectives and routines, by accepting extended periods of extreme low flows in the river, accepting a river without a sustainable salmon population and changing freight transport to railways or roads during extreme low flow events. If such developments are

[15] INTERNATIONAL RHINE BASIN CONFERENCE. Water Shortage and Climate Adaptation in the Rhine Basin. Kleve, 29–31 October 2012

considered unacceptable adaptive action needs to be taken, by implementing one out of the (non-exhaustive) list of strategic adaptation options in table 3.

Table 3: (non-exhaustive) list of strategic adaptation options (numbers relate to figure 5)

| Adaptation Option | Description |
|---|---|
| **Reservoir management** | Reservoir management. The Rhine River basin has more than 2000 artificial reservoirs (ICPR 2009) constructed for hydropower or water retention purposes. Increasing outflow to mitigate extreme low discharges will potentially delay threshold crossing, but due to limited volumes of water impact on delaying thresholds will be short |
| **Ground water infiltration** | Ground water infiltration is increasing the base flow of the river also in times of droughts. Depending on the quantity of water infiltrated this strategy potentially has a long lasting impact. Decision taking will require several policy and planning cycles because decisions need to be taken at many levels. Most measures (reforestation, reducing drainage, artificial infiltration) have to be implemented locally, and only after a significant quantity of projects impacts on the main river discharges will be felt (Thomas et al. 2011). |
| **Water temperature policies** | Reduction of anthropogenic warm water discharges in the river. Current river water temperature standards are based on research in the 1970s on toleration limits of (cyprinid and not salmonid) fish (Vonk et al. 2008) and are set at a maximum of 28 °C. Reduction of point source discharge, enforced by more rigid standards, by investments in cooling towers or reductions of warm water discharges will temporarily have an effect on water temperature. |
| **Adapt morphology** | Shading of small rivers and brooks. Creation of cool places in the river (deep lakes, protection of groundwater inflow zones) (see Bölscher et al. submitted) |
| **Canalization** | Canalization of sections of the Rhine at potential navigation bottlenecks (Kaub, Nijmegen) by construction of weirs and locks. Decisions will need to go through several policy and planning cycles and construction of infrastructure will require time. The strategy is effective for navigation, but may have adverse effects on salmon policies (Riquelme-Solar et al. to be submitted). |
| **Innovations in inland shipping** | Adaptations in vessel designs may reduce needed water depth, but will have an trade off with performance in times of sufficient discharge. Also industries may decide to enlarge stocks of goods to cope with longer periods without shipping (Riquelme-Solar et al. to be submitted). |

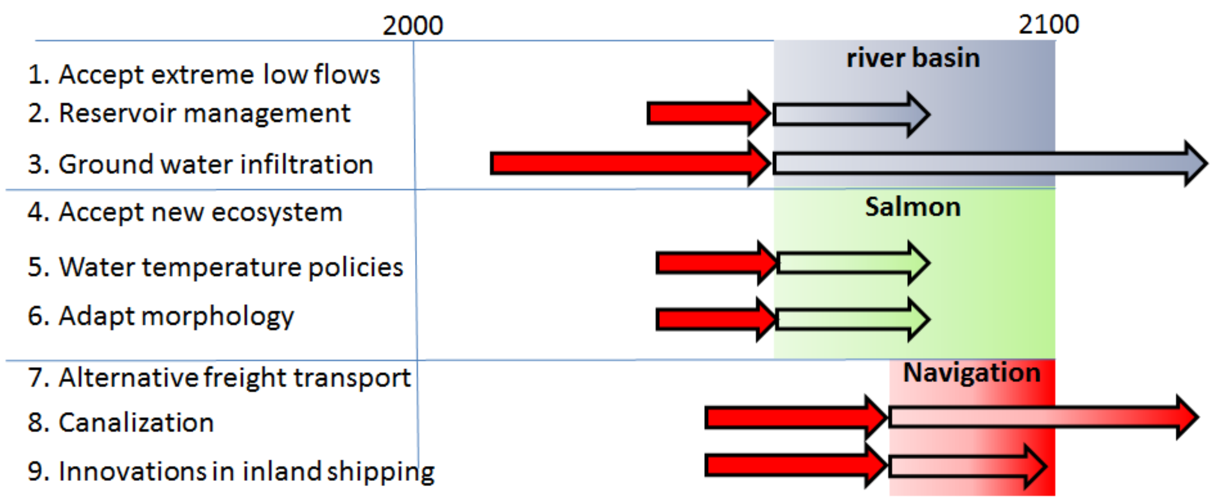



**Figure 5**. Indicative presentation of strategic adaptation options. The three colored rectangles indicate types of management regimes: blue for the river basin as a whole, green for salmon reintroduction and red for navigation. The red arrows show estimates of time needed for implementation and the colored arrows indicate time of delay of threshold crossing after implementation.

*Reflection on results*

The decision pathway indicates "real option analysis" as the appropriate method (see figure 4). The aim of analysing real options (Dixit and Pindyck 1994) is to compare costs and benefits of adaptation pathways and to assess the value of the flexibility of options. The aim of real options analysis is to know the value of waiting for more information before making a decision.

The research question of this case study is about 'timing' of decision making and not so much on costs and benefits and the value of waiting. The results of this case study can be seen as a first step in real option analysis, as it identifies logical sequences of adaptation options.

The relevance of figure 5 for river basin managers is an assessment of the urgency to make decisions. The first choice is to make no decision at all, and let the threshold pass, causing a forced transformation of management objectives. But if management regimes want to maintain its objectives for the long term, adaptation is in order.

On the basis of actual knowledge these crossings are expected in the second half of this century. From a river managers point of view the urgency to act is low, and there is still time to consider options or to do more research on alternatives and impacts. An important moment occurs around 2020-2030, when decision taking on ground water infiltration must be put on the policy agenda. If the process of groundwater infiltration policy making does not start in this period theoretically the window of opportunity passes and this option is no longer valid, reducing the total number of options. Ground water infiltration is potentially the most effective option, as it pushes the time of threshold crossing both for salmon reintroduction policies and navigation to a faraway future. Other options with far reaching consequences (accept new ecosystems and canalization) are directed at one sector only and may affect other sectors adversely. Canalization for example will reduce ecosystem quality.

The estimates of threshold delays caused by strategic adaptation options in this case study are based on expert judgements. Assessments can also made with model projections, thus increasing the accuracy of time estimates. Also the periods needed for implementation are qualitative estimates. More research on governance processes in international rivers can improve on the accuracy.

**Discussion**

Appraising adaptation options in the Rhine river basin is a challenge because of the interdependency between sectors and between regions. International river basin commissions need to make choices while considering multiple objectives. And analyzing thresholds in a management regime, as if such a regime would function independently neglects cross sector feedback mechanisms.

Also the behavior of the rivers hydrology in times of drought is complex and is not well analyzed yet (Görgen et al. 2010).Potential impacts of adaptation strategies, like groundwater infiltration are not known yet for the river basin as a whole. Research on catchment level only indicates the potential for larger scale implementation (Thomas et al. 2011).

These elements (polycentric governance, interdependencies and knowledge uncertainties) make integrative assessments of adaptation options for extreme low flows a complex undertaking. The results of this case study with its limited scope on only two sectors, reflect the uncertainties and difficulties mentioned.

Following the decision pathways of the Adaptation Task Navigator one ends up at robust decision making and real options analysis as best methods to appraise adaptation options. Both methods start from the premise that management regimes may not have all, but do have sufficient, information to take decisions on adaptation strategies. And that decision makers are in need of a full appraisal of options. This case study suggests an extra step. It assumes that analysts do have sufficient information to appraise options, but it asks whether there is a need to take decisions. One can choose to do nothing or wait. In other words it introduces a timing element and assesses the level of urgency. In their research on a typology of adaptation problems (Patt et al. 2011) find policy makers do tend to react on the basis of a sense of urgency. This assumes that issues will only rise high enough on the political agenda when the pressure (from media, public, experts, or combinations thereof) on relevant political arenas is sufficiently high (Kingdon, 1995). Identification of decision moments as in figure 5, does not open windows of opportunity and is no guarantee for creating the necessary sense of urgency, but it at least analyses when such moments must occur at the latest to be able to consider all possible options.

The identification of management regime thresholds allows for deep uncertainty (Walker et al. 2013). The type of uncertainty in which analysts do not know what knowledge is needed and do not agree on problem definitions, nor on outcomes of analyses. In such conditions 'predict and act' is not possible and 'monitor and adapt' seems more appropriate. The ranking of adaptation options in terms of time for decision taking provides a framework for monitoring, as it allows to analyze changes in thresholds and in decision timings.

Sector studies on climate change impacts for navigation and ecological quality do not raise alarm bells yet. Vries and Buitendijk (2012) concludes that before 2050 no climate induced problems will occur and no adaptive action is needed (Vries and Buitendijk 2012). For salmon reintroduction policies no relevant studies are existing yet, though the ISKR as assigned research on water temperature projections.

This case study indicates that if Rhine river managers want to avoid major changes in policy objectives the first decision moment for adaptation will occur within a few decades. As it is now there is no sense of urgency yet. There was some alarm after a very dry summer with an extended period of low discharges and high water temperatures. After 2003 power companies lobbied Dutch government with success, and maximum water temperature standards in extreme conditions were raised from 25 $^{0}$C to 28 $^{0}$C. When more such events will occur the coming years, one may expect political attention and maybe a window of opportunity for adaptive action.

Another strategy – proposed at the International Rhine conference – is to mainstream adaptation by connecting it with other policies. Examples are:

- including standards for infiltration of rainwater on agricultural lands in the Common Agricultural Policy definition of good agricultural practices;
- combining wetland and flood plain construction for flood security and ecological restoration with retention of water in times of drought.
- Using the implementation of green infrastructures (like the Natura 2000 network) for infiltration of rainwater and retention.

**Conclusions**

This case study on climate futures of salmon reintroduction and navigation finds these futures are at risk, at least without adaptation. On the basis of transient projections of water temperatures and discharges risks of thresholds crossing are found in the second half of this century. Variability's in model outcomes are high and no well-defined point in the future is determined. But as risks of threshold crossings are significant questions about adaptation options arise. The first option is do nothing and accept crossing of thresholds, which means the actual management objectives (sustainable population of salmon, continuous operation of inland shipping) will have to change. Other options are to take adaptive action. The first decision moment for increasing rainwater infiltration to groundwater in order to increase the rivers base flow occurs within a few decades. If no policies are made the number of options decreases gradually.

Looking for management regime thresholds adds a method to the formal appraisal of adaptation options. Threshold analysis puts emphasis on the timing of decision taking and measures the level of urgency.

## The Wadden Sea case

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Albert Oost (Deltares)

**Introduction**

There is a demand for methods and tools to assess and communicate the implications of climate change for decision-making. Concerned decision makers increasingly pose questions as to whether current management practices are able to cope with climate change and increased climate variability or whether alternative strategies are needed. They urgently demand reliable science-based information to help them respond to climate change impacts and opportunities for adaptation (Dessai *et al.*, 2004). The linking of science with user needs is a multifaceted problem with no simple solutions. [xx ref Science-policy interface]

Many different tools and methods exist to structure the process of providing decision support.

This paper aims to analyse the adaptation decision-making process in the Dutch Delta Programme for the Wadden region as a case for the diagnostic framework. The Delta Programme is currently being designed to protect the Netherlands from flooding and to ensure adequate supplies of freshwater in the prospect of climate change (Delta Commissioner, 2011). As an example of adaptation decision-making it offers an attractive case to reflect on tools and methods used in practice. In particular this paper focuses on the knowledge questions addressed during the first three years of the decision-making process, and the associated tools and methods. It will re-narrate this process using the steps and decision trees in the diagnostic framework [xx check relationship with Adaptation Task Navigator (ATN) & how to refer to this, as I am using the steps on of framework as shown on web for ATN] and will reflect on reasons to divert from the diagnostic framework.

To do so, we will follow the steps and decision trees of the ATN. The sections below will first describe the case study and the application of the ATN to the case. Next it will discuss results focussing on the xx. Finally this paper offers lessons learned from the assessment and consequences for the diagnostic framework developed.

We observe that the use of methods in the adaptation planning process can be explained quite well by the decision trees of the diagnostic framework. Diversions occur when the selection of tools is informed by practical limitations of the decision making process, such as available resources and experience of the involved experts.

**Methodology**

*The Delta Programme and the regional study for the Wadden region*

This assessment is carried out for the Dutch Wadden region. The Wadden region is one of the world's largest tidal areas of its type consisting of mudflats borders by barrier islands in the North and the coast of the mainland in the South. It has been on the Unesco World Heritage List since 2009. The assessment focuses on adaptation planning in the Wadden region, as addressed in the Dutch Delta Programme. In

2007, the Dutch government installed a commission with the request to formulate recommendations on protecting the coast and the entire low-lying part of The Netherlands against the consequences of climate change. Based upon their advice an integral policy programme (Delta Programme) was designed, executed by the Dutch Ministry of Infrastructure and the Environment and the Ministry of Economic Affairs, Agriculture and Innovation. The overall objective of the Delta Programme is to protect the Netherlands from flooding and to ensure adequate supplies of freshwater for future generations in the prospect of climate change (Delta Commissioner, 2011). A Delta Commissioner was appointed to oversee the implementation of the Delta Programme. His main responsibility is to prepare an annual report that outlines progress and the steps that will be taken in the year ahead. The report is offered each year to the House of Representatives as part of next year's national budget. This is at the most important moment for parliamentary policy making, as MPs can amend the budget to finance specific plans.

The Wadden region is one of the regional sub programmes of the Delta Programme (Figure 18). The central goal of the Delta Programme in the Wadden region is to warrant long-term flood safety and to establish a monitoring programme for the impact of climate change on the ecology of the Wadden Sea in particular. Special attention goes out to adaptation strategies based on natural process that can strengthen ecological resilience in the area and facilitate sustainable human use. Recreation and tourism are the most important economic sectors on the islands. Other activities in the Wadden region are agriculture, fisheries, industry, shipping, and energy production and transfer (mostly linked to the ports in the region). Table 7 provides an overview of the typical water management activities in the region.

A substantial amount of studies have addressed the possible consequences of climate change for the Wadden area and the economic activities in the region. Regional base lines studies have been carried out for the Delta Programme (Oost *et al.*, 2010) and the Quality Status Report Wadden Sea (Oost *et al.*, 2009). The main climate pressures on the Wadden region will be (van den Hurk *et al.*, 2006; KNMI, 2009) i) temperature rise, ii) sea level rise, iii) changes in wind and wave climate, including heavier storm surges and wave set-up, and iv) precipitation increase in winter, decrease in summer. Increase of heavy rain showers.

Below we summarise impacts of climate change on the three main objectives of the Wadden region: safety, nature and sustainable human use.

***Potential climate change impacts on safety***

It is very likely that more sediment is needed in the Wadden Sea to compensate sea-level rise (Kabat *et al.*, 2009; Oost *et al.*, 2009). This is expected to result in increased erosion of the islands and additional requests for sand replenishment (Ministerie van Verkeer en Waterstaat, 2008). There is a limit to the rate of sea level rise that the natural sedimentation in the Wadden Sea can compensate for. If sea level rise is not compensated by sedimentation, tidal exchange through inlets increases, which leads to sand sequestration in ebb-tidal deltas and (further) erosion of adjacent barrier shorelines. Increased erosion and channel formation can undermine sea walls. The combination of projected sea level rise, storm occurrence and heavier storm surges compromise the safety of ports and industry in unembanked areas outside the sea walls (Oost *et al.*, 2010). A special case is the Ems, a tidal river on the border of the

Netherlands and Germany. Due to its location, dredging and other interventions the tidal build up of water is already high (Talke and Swart, 2006). The estuary has a significant role in energy production and transport. Increased storm frequency will endanger infrastructure in the estuary. The impacts of temperature rise and precipitation change on safety and the primary sea walls are less well understood and presently expected to be low (Oost *et al.*, 2010).

***Potential climate change impacts on nature***

Climate change adds a pressure to the coastal ecosystems that are already heavily modified by human interventions (such as fisheries, nutrient enrichment, contamination and the introduction of non-native species). It will stress the present structure and functioning of the food web and may result in a cascade of yet unknown effects. Shifts in the geochemistry of sediments, in primary production and in the occurrence of fish, mammal and bird species are explored yet remain largely uncertain (Philippart and Epping, 2009). Such shifts in ecosystem functioning would inevitably have consequences for possibilities and limits of sustainable use and for the protection of natural ecosystems and their services. A key factor is whether natural sedimentation of the mudflat areas will keep up with sea level rise or whether the tidal marshes will disappear, significantly changing the character of the Wadden Sea. A contributing factor is that at many places dykes, artificial dune rows and other human intervention hinder natural sedimentation on the island. In general the lack of natural dynamics enhances succession, leading to lower sedimentation rates in dunes, wash-overs and tidal marshes and loss of habitats for rare species and pioneer conditions (Oost *et al.*, 2009; Dobben and Slim, 2011).

Climate change can also affect water quality in the Wadden Sea. High precipitation and river discharge will require discharge of freshwater from inland water bodies. Sudden release of fresh water volumes affects salinity levels, which can periodically damage fauna. The Ems Estuary is at particular risk as dredging has already resulted in periods of low food and oxygen levels eradicating estuarine life (Oost *et al.*, 2010).

Lastly, impacts of temperature change are reported. The effect of an increase in water temperatures on water viscosity and the settling and resuspension rate of sediment may lead to a shift in the timing of sediment redistribution and of stabilization, which may have consequences for the pelagic (via effects on turbidity) and benthic (via effects on habitats) biomass and production. Also species composition may shift with temperature change (Philippart and Epping, 2009). Although these effects have been addressed in individual studies, the location specific impacts of temperature change presently are highly uncertain.

***Potential climate change impacts on human use***

Impact studies mostly report consequences for agriculture, fisheries, energy production, industry and freshwater supply due to periods of drought and water stagnation, salt intrusion, higher seawater temperature and/or flood risk in unembanked areas. The Wadden Sea is an important fish spawning ground and migration route. Less mudflats and higher water temperatures will have consequences for the fish population and species composition. This will impact fisheries in its current form. With heavier precipitation, the risk of water stagnation increases impacting agriculture and other land uses. At the same time, droughts can add to soil subsidence and salinisation with implications for nature, agriculture and water supply. Presently 20% of energy production in the Netherlands takes place in the Ems estuary. Policy plans are to increase the share to 30%. In addition, raw materials for energy production are transferred along with exploitation of natural gas in the coastal zone. The Wadden region features a number of larger industrial zones. Industry and energy supply add to storm and flood risks.

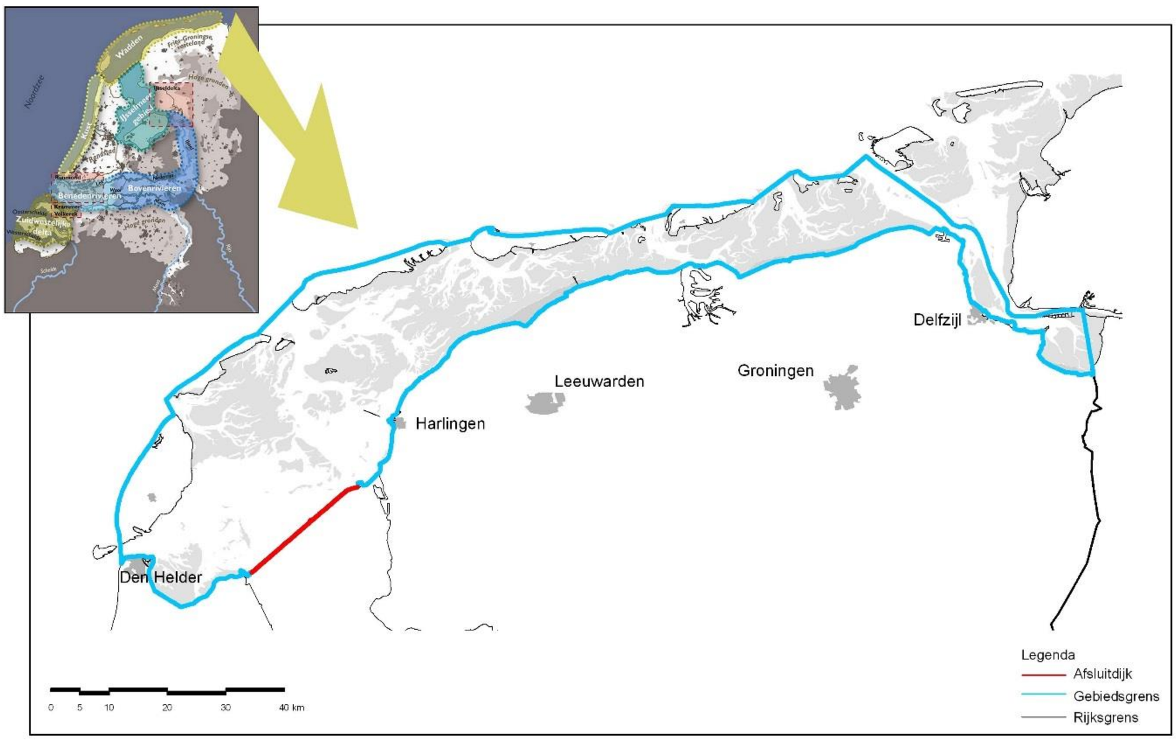


*Figure 18: The Wadden region as defined by the Dutch Delta programme*

*Table 7: Current management activities*

| Goal | Typical measures activities in current management |
|---|---|
| Safety | Sea walls protect the Netherlands against the North Sea and the Wadden Sea. On the islands, the primary flood protection consists of dunes (along the North Sea) and dikes (along the Wadden Sea). Characteristic for the islands are the so-called drift dikes or dune dikes that were built in the past and that may stretch for several kilometres along the coast. The mainland coast of the Provinces of North Holland, Friesland and Groningen is protected with the longest dike in the Netherlands, running from Den Helder to the Dollard. Sand replenishment is practised to maintain the coastline, also under sea level rise. |
| Resilient | The recognition of the Wadden Sea as World Heritage, the Natura 2000 regulation and the Water Framework Directive set the standard for nature conservation. Measures will |

| | |
|---|---|
| nature | be developed in framework of the policy programme 'Towards a rich Wadden Sea'. Interventions focus on nature restoration and fisheries management, through covenants and regulations. |
| Sustainable human use | The conditions are set by the provinces and municipalities, mostly captured in so-called 'coastal visions'. Sectoral plans and regulation are developed for, amongst others, gas exploitation and fisheries. |

***Governance of Delta (sub)programme***

The Delta Programme aims for national government leadership for strategic long-term decisions. The guidelines for the implementation process follow the policy advice 'Faster and Better' (Sneller en Beter`, Deelstra *et al.*, 2009) to speed up decision-making processes by exploring strategic alternatives and early selection of one development direction to be advanced in an implementation plan. Such early strategic guidance differs from the prevailing Dutch infrastructural planning practice that typically postpones decision making until several (regionally negotiated) alternatives have been developed and appraised in greater detail (cf. Deelstra *et al.*, 2009). So far, the involvement of agents from civil society and business in the Delta subprograms is limited. Here the implementation diverts from the advice 'Faster and Better' that recommends early active involvement of these agents in exploratory regional development activities (Deelstra *et al.*, 2009).

The Delta Programme is organised in ten subprograms. Four of these are generic subprograms and six are regional subprogram (see Table 8). The generic subprogram 'Delta Act' started ahead of the other subprograms to provide the legal foundation for the Delta Programme, define the authorisations of a Delta commissioner to be appointed for the program, and set out the plan for financing the measures to be taken in the Delta Programme.

*Table 8: Delta Subprograms and their objectives*

| *Generic subprograms* | *Objective / Strategic decision* |
|---|---|
| Delta Act (*Delta wet*) | Provide the legal foundation for the Delta Programme, define the authorisations of a Delta Manager, and set out the plan for financing the measures to be taken in the Delta Programme |
| Watersafety (*Waterveilig-heid, incl. Buitendijks*) | Develop policy to reach and maintain flood safety of a societal and political accepted risk level |
| Freshwater supply (*Zoetwatervoorziening*) | Develop and explore strategic alternatives for the long-term freshwater supply (incl. salinisation) |
| (Re)development plans (*Nieuwbouw en herstructurering*) | Develop an appraisal framework and stimulate decision making and investment in (re-) development that prevents -in time- passing on costs, risks and impacts of climate change |

| *Regional subprograms* | |
|---|---|
| Coast (*Kust*) | Explore the conditions for maintaining long-term coastal safety and the desirability, feasibility and costs of seaward expansion of the coast |
| Rijnmond / Drechtsteden | Securing long-tern water safety and creating boundary conditions for sustainable water supply in the region as a contribution to sustainable and dynamic spatial development. Focus Sea - River Rhine interface. |
| Wadden Sea region (*Wadden*) | Sustain the long-term water safety of the islands and the coast along with the region's natural value |
| Southwest Delta (*Zuidwestelijke Delta*) | Secure and climate-proof the long-term water safety and the conditions for freshwater supply to strengthen the region's economy and ecology |
| Rivers (*Rivieren*) | Integral long-term (2100) problem analysis for the major rivers including (spatial) strategic alternatives and decisions |
| Lake IJsselmeer | Explore the effects of raising the lake water level and the alternative futures for its seaward closure dam (*afsluitdijk*) |

The subprograms are supported with guidelines and a general time schedule, offered by the Delta Commissioner and his staff. The guidelines are gradually becoming available. Beyond this the subprograms operate relatively independent and can design their own sub-bodies and responsibilities for the implementation.

A Ministerial steering group chaired by the Prime Minister has been created to head the implementation of the Delta Programme. The political responsibility and coordination of the Delta Programme is in the hands of the State Secretary[16] of the Ministry of Infrastructure and the Environment. In practise, two ministers and one state secretary together act as the executives for all subprograms. The instruction to organise a subprogram is for each subprogram commissioned to a high level administrative agent in the responsible Ministry (typically a Director General or a Department Director, called *controller* here (in Dutch: *gedelegeerd opdrachtgever*)). Together the administrative controllers form the Director General Counsel that prepares the Ministerial Steering Group. The controllers are also responsible for overseeing the process in the subprograms and contracting an agent for the implementation (called *contractor* in this paper (in Dutch: *opdrachtnemer*)). In practise the contractors of the subprograms are civil servant from the national government.

[16] Within the Ministry of Infrastructure and the Environment the State Secretary is responsible for the Theme Water. Hence the State Secretary coordinates the Delta Program rather than the Minster.

By November 2009, each subprogram had prepared its instruction and had put it before the Director General Counsel for approval. Comparing the instructions it is concluded that the regional subprograms are similarly organised (see Figure 19).

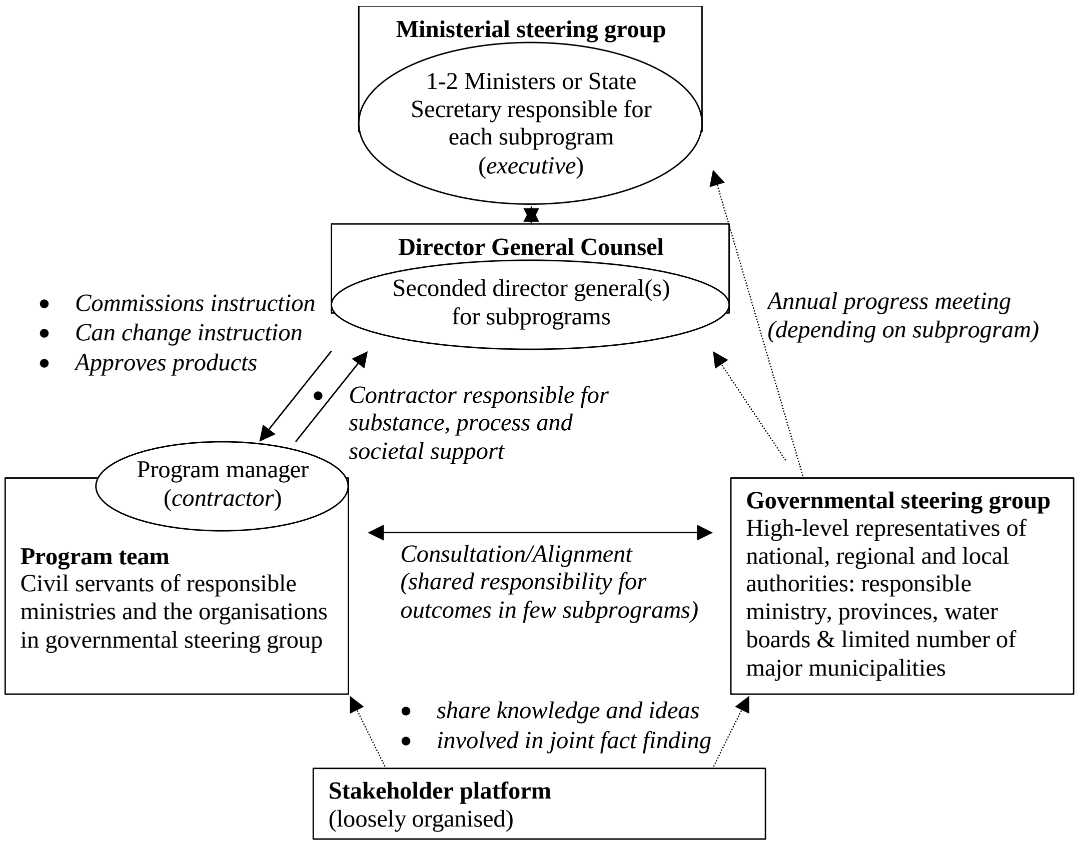


*Figure 19: Governance architecture of subprogram*

*Assessment*

This study aims to discuss adaptation planning and decision support in the Wadden region under the Delta Programme. The assessment is based on literature review and the interaction with decision makers and other stakeholder representatives in the context of the Dutch Delta Programme for the Wadden region. Xx Use policy documents and background studies produced as part of the policy process. Use English text where available. Interviews, participation and consulting in the policy process.

Xx we will make use of the annual cycle of the Delta Programme and analyse the work done in the individual years. Table 9 lists the consecutive years that are used in the analysis. It has to be noted that the programming and execution of the research for a next Delta Programme report often starts in parallel with the governmental preparation of the Delta Programme in progress. That is, research for Delta Programme 2013 will start early 2011 to be ready end of 2011 to be included in the writing process. Similarly, at the start of the research for Delta Programme 2013, civil servants will still be working on Delta Programme 2012.

*Table 9: Consecutive years in the analysis*

| | | |
|---|---|---|
| Year 1 | End 2009 - summer 2010 | Towards Delta Programme 2011, presented Sept. 2010 |
| Year 2 | 2010 - summer 2011 | Towards Delta Programme 2012, presented Sept. 2011 |
| Year 3 | 2011 - summer 2012 | Towards Delta Programme 2013, presented Sept. 2012 |
| Year 4 | 2012 - summer 2013 | Towards Delta Programme 2014, presented Sept. 2013 |

Xx using the steps in the diagnostic framework [xx check relationship with Adaptation Task Navigator (ATN) & how to refer to this, as I am using the steps on of framework as shown on web for ATN] + reflect on reasons to divert from the diagnostic framework.

**Results**

*Overview*

Figure 20 provides an overview of the steps taken in the case study. Each step represents a year in the annual cycle of the development in the Delta Programme. The figure shows the evolution of the central question to be addressed (Delta Commissioner, 2010; Delta Commissioner, 2011; Delta Commissioner, 2012). Thus it illustrates the stepwise interpretation and reframing of the adaptation challenges. Each year asks for new knowledge to be generated. The methods selected in the different years are analysed in more details in the sections below.

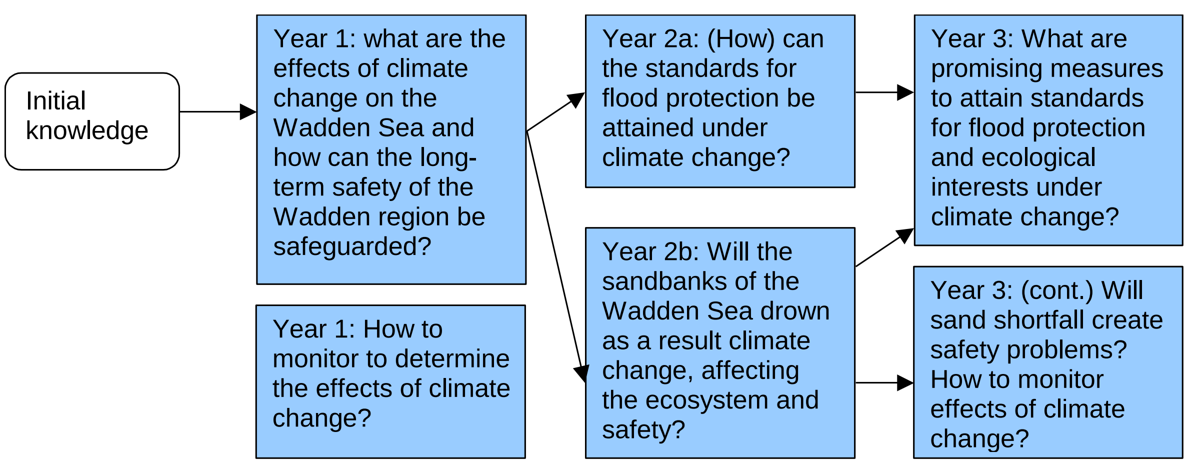


*Figure 20: Main steps and knowledge questions in the Wadden case study*

*Step 1 - Year 1 of adaptation planning in the Delta Programme*

Year 1 focused on the adaptation challenge '*what are the effects of climate change on the Wadden Sea and how can the long-term safety of the Wadden region be safeguarded*?' (Delta Commissioner, 2010). Figure 21 illustrates the path through the decision tree in the first year.

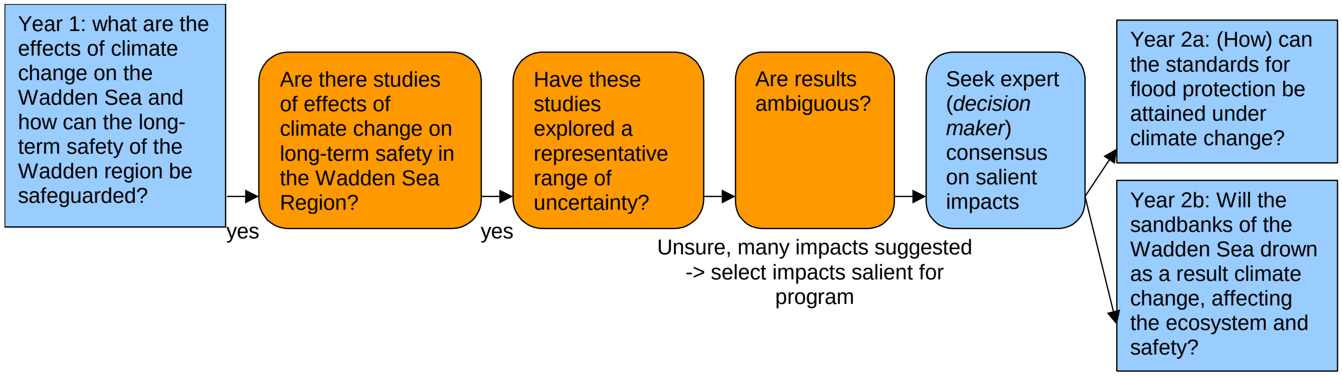


*Figure 21: Analysis of the tasks undertaken in the first year of the Wadden case study (Step 1), using the Adaptation Task Navigator (ATN) of the diagnostic framework*

Year 1 is characterized by scoping and background studies that summarise available knowledge on impacts and trends of climate change. This process yielded a long list of reported (potential) impacts (Oost *et al.*, 2010). Faced with the complexity of reported impacts in the background studies for the Delta Programme, it was felt more focus was needed in the course of the policy process. The programme team decided to prioritised impacts for closer study in the Delta Programme. The prioritisation is based firstly on its direct impact on the central goals of the Delta Programme (safety norms and freshwater supply), next on the severity of the impact and its likeliness. Direct impacts on human uses were considered out of the main scope of the Delta Programme for the Wadden Region and are as such not explicitly targeted by adaptation planning or support studies. At the same time, the sub-programme specifies that the adaptation measures that are considered in the programme are also to be evaluated against producing co-benefits for sustainable human use and coping with impacts of climate change on economic sectors in the region. These sectors will come back in the assessment in later years.

Thus, Year 1 was dominated by literature review and seeking expert opinion. Although the Delta Programme deals with long-term climate change already the pressure of the annual implementation cycle was felt. Results include prioritised impacts and a more focussed problem definition for the coming year. With respect to knowledge development, we observe that the ministries rely strongly on their ‘own’ knowledge institutes and epistemic communities. Few -if any- social scientists are actively involved in the research of the first year and little social sciences research is commissioned (Werners *et al.*, 2009). This not withstanding, the program team engages in the organisational setup of involvement of different parties in the coming years.

Methodologically, an important development in the first year was the initiative of the central staff of the Delta Programme to start the co-development of various guiding documents, most significantly on base values and criteria for the evaluation of adaptation, on the assessment of adaptation tipping points, and on adaptive delta management. Although these guidance documents only became available in the second and third year of the Delta Programme the guidance and interaction organised by the central staff bureau increasingly helped to focus the work towards adaptation decision-making.

Xx include some detail on focus of assessment of adaptation tipping points. This focus is reflected in the two central questions for Year 2.

*Step 2 - Year 2 of adaptation planning in the Delta Programme*

Shortly after the first Delta Programme report was delivered (at the end of Year 1), the Government Commissioner Wim Kuijken said[17]:

*"One of the biggest challenges is dealing with uncertainties in the future climate, but also in population, economy and society. This requires a new way of planning, which we call adaptive delta planning. It seeks to maximise flexibility; keeping options open and avoiding 'lock-in'. In the meantime, we prepare the so-called delta decisions about the measures to take if our current water system reaches its limits."*

This quote signifies two things: 1) recognition by the central staff that a new planning approach had to be developed and adopted, 2) a new framing the adaptation challenge, as the finiteness of the current water management system under climate change. After the first year the Delta Programme even more clearly saw the need to define its own niche and scope and encouraged the sub-programs to assess how much longer current policies and management practices were expected to suffice and when adjustments would be required. This relates to the recognition that climate change will become salient for practitioners if it threatens management objectives or results in conditions that society perceives as unacceptable. It presumes that adaptation becomes relevant only if the amount of change is unacceptable or interest can be realized more effectively by alternative management options (Werners *et al.*, 2013b).

This focus can directly be seen in the questions for Year 2 in the Wadden Delta Programme: *1) Can the standards for flood protection be attained under climate change?*, and *2) Will the sandbanks of the Wadden Sea drown as a result climate change, affecting the ecosystem and safety?*. Figure 22 illustrates the path through the decision trees in the second year.

[17] Deltas in Times of Climate Change conference held in the WTC in Rotterdam, the Netherlands, Wednesday 29 September 2010, www.deltacommissaris.nl/english/news/presentations/thedeltaprogrammeinthenetherlandsthedeltaworksofthefuture.aspx

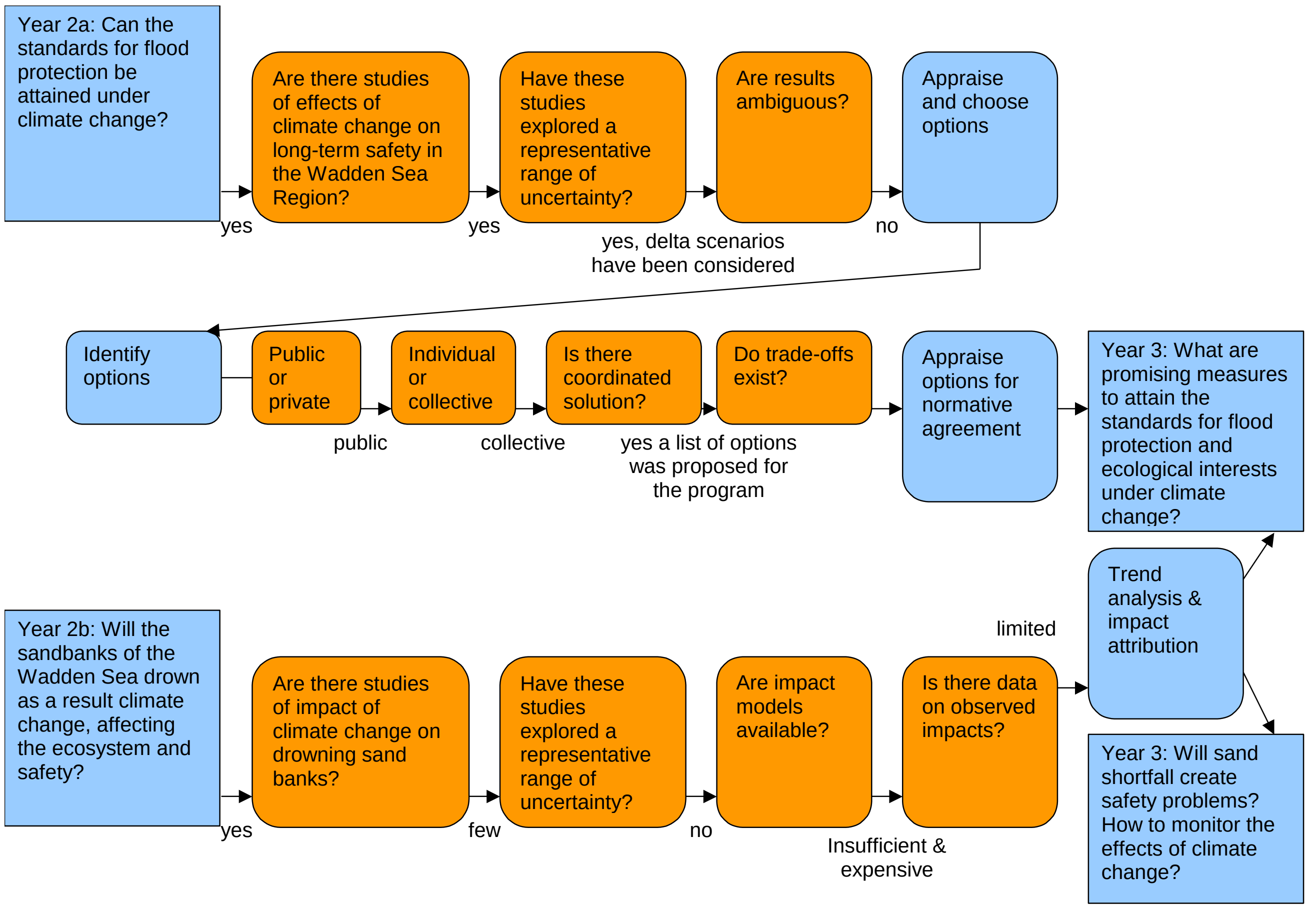


*Figure 22: Analysis of the tasks undertaken in the second year of the Wadden case study (Step 2), using the Adaptation Task Navigator (ATN) of the diagnostic framework*

In terms of the decision trees, the Delta Programme in Year 2 started with another cycle of research at the entry point '*Appraising vulnerability and impacts*'. Again the same steps were addressed. What was new is that at this stage there was more focus in the research questions as well as in the guidance provided by the central staff. Significantly, the delta scenarios had become available, which changed the situation compared to the previous year. In the second year, the program team of the Wadden region also intensified the work on adaptation options. Adaptation options had been addressed in general terms before, yet only in the second year were they in to be addressed explicitly by research [xx ref to research agenda developed for the second year]. This is in line with the decision trees and the suggested progress to the second entry point '*Appraising and choosing adaptation options*'. The Delta Programme has been initiated by the national government and focuses mostly on collective public action. Emphasis in the second year was on studying a list of possible adaptation options in more detail. These options are broad alternatives, rather than specific measures. It is the objective of the Delta Programme to consider a number of strategic alternatives and make decisions at a more strategic level, e.g. to change major water works or shift from freshwater distribution to regional self-sufficiency. It will leave detailed implementation to the regular water management policy process. No attempts were made to compare between alternatives in the second year. In parallel with studying alternatives, the central staff facilitated the development of criteria for comparison of alternatives. The second year saw increased involvement of the central staff, encouraging co-ordination and harmonisation across sub-programs. Involvement ranges from comparison of research agendas, the development of guidance documents (e.g. te Linde and Jeuken, 2011), the harmonisation of terminology and providing central facilities for hydrological model calculations and cost assessments. In addition, knowledge-sharing systems were tested to improve transparency and credibility of the work.

Although the assessments in Year 1 and 2 showed that climate change is expected to compromise current policy objectives and stakes in the Wadden Sea region in the coming century, the seriousness of the impact and timing are largely uncertain. Therefore the Delta Programme has decided to augment possible adaptation options with setting up a monitoring program with the specific objective of early warning of impacts of climate change and impacts thresholds in particular. Monitoring is seen as an appropriate immediate adaptation strategy given both the uncertainties and the potential severity of impacts.

A diversion from decision trees in the Wadden region was a series of quick scans for each of the topics on the research agenda to tap into available knowledge, to share ideas and define knowledge gaps. Another activity with little attention in the decision tree is the development of a method for eliciting and co-developing alternatives.

The pressure of the annual implementation cycle was felt even stronger than in the first year. This also influences the methods selected as more fundamental studies of system behaviour were estimated to take too long to be included in an annual reporting cycle. Interaction with the steering group of the sub-program as well as the staff of the Delta Commissioner has co-determined the pace and emphasis of the research questions. In particular the Wadden Region steering group commented that more attention should be paid to the social and economic consequences (also at a national level) of a failure in energy production and distribution in the northern part of the Netherlands in the case of flooding. Secondly, the flooding calculations must be rechecked, as the assessments showed different flood patterns than the region so far expected. These issues will be taken up as part of the appraisal of options and the identification of co-benefits, e.g. for the energy sector.

*Step 3 - Year 3 of adaptation planning in the Delta Programme*

The guidance on Adaptive Delta Management that had been announced in the second year became progressively clear in Year 3 (Rhee, 2012). This provided a comprehensive, yet unbinding, timeline for the sub-programs (See Figure 23). Key points of adaptive delta management are (Delta Commissioner, 2012; Rhee, 2012):

- Linking short-term decisions with long-term planning around flood risk management and freshwater, taking into account uncertainties in climate and socio-economic scenarios;
- Working with adaptation pathways that consist of multiple strategies that can be alternated between, actively timing decisions and using windows of opportunity;
- Identify and appraise flexibility in adaptation options and pathways, e.g. possibilities for speeding-up/slowing down or step-wise implementation of an option depending on observed change and new information;

- Actively investigate and appraise opportunities to link investment agendas of public and private parties to capitalise on synergies and innovative investment schemes.

For the Wadden region the implications of these key points in Year 3 are a new interest in private parties.

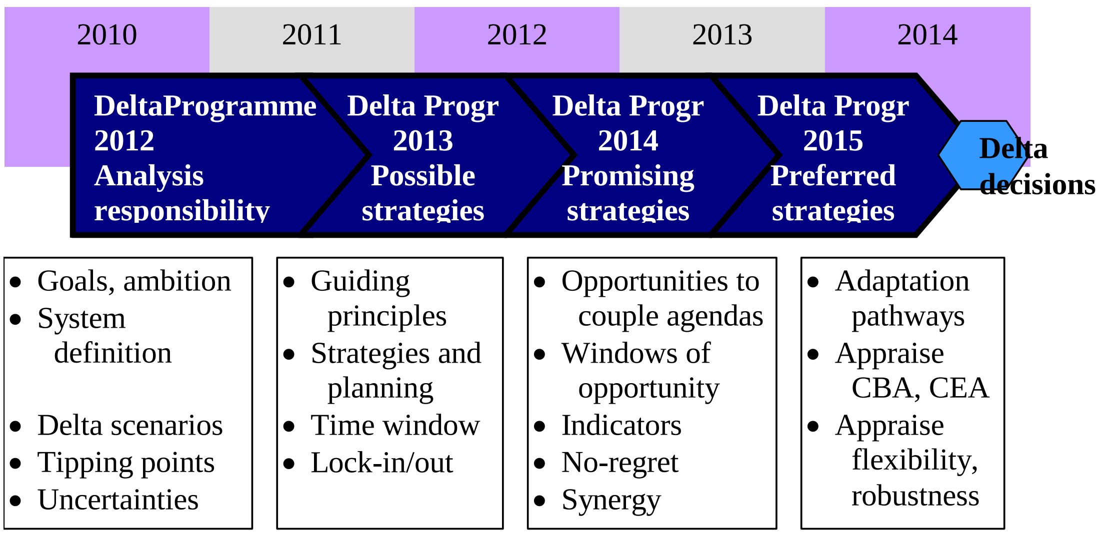


*Figure 23: Comprehensive planning of Delta Programme products (Source: Rhee (2012))*

In line with Figure 23, the questions to be addressed in the Wadden Delta Programme in Year 3: *What are promising measures to attain the standards for flood protection and ecological interests under climate change? Will sand shortfalls create safety problems? How to monitor effects of climate change?* Figure 24 illustrates the path through the decision tree in the third year.

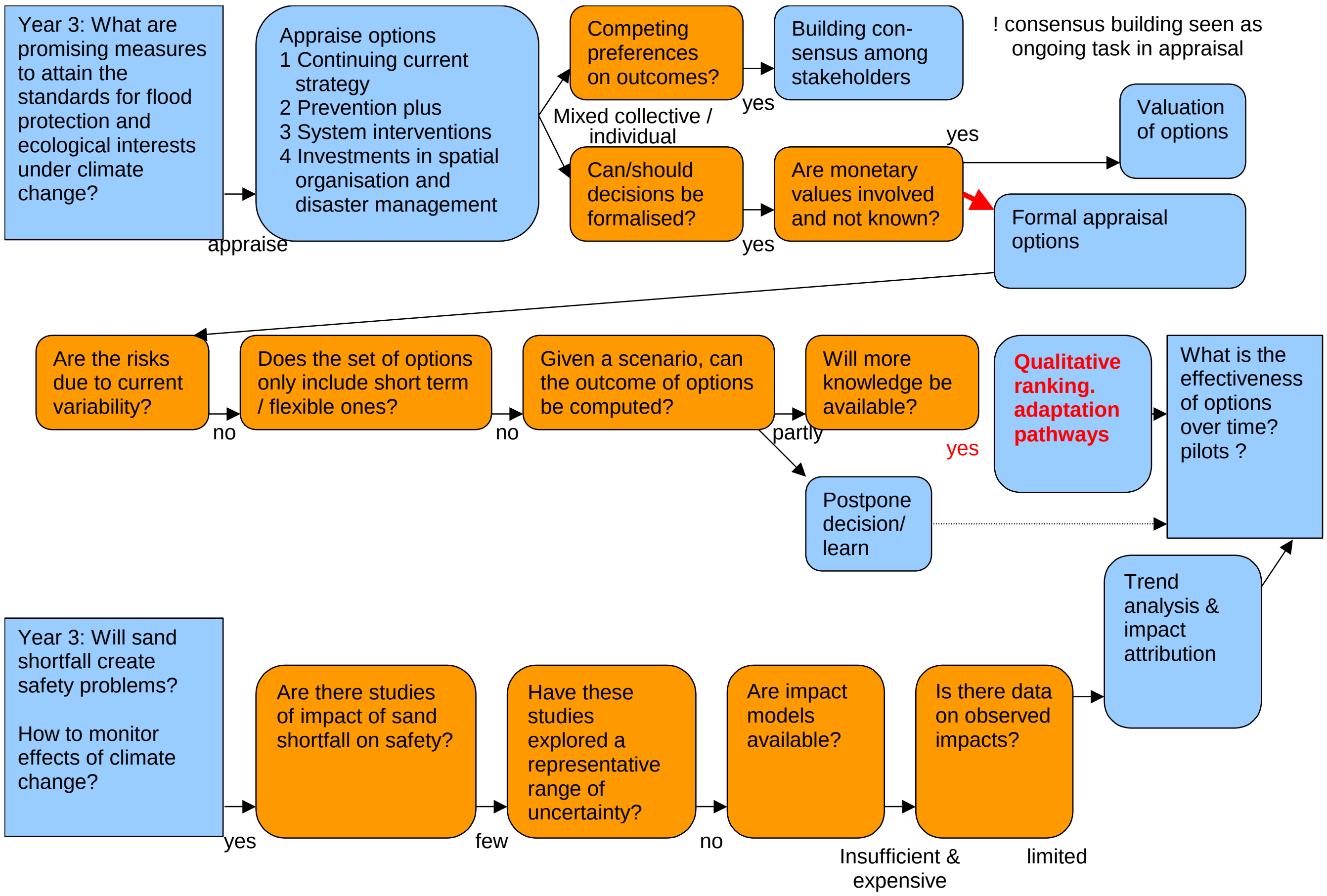


*Figure 24: Analysis of the tasks undertaken in the third year of the Wadden case study (Step 3), using the Adaptation Task Navigator (ATN) of the diagnostic framework*

Year 3 focussed on the appreciation of strategies. At the same time discussions on system knowledge and the appreciation of the current safety challenge continued. The program team reorganised the research agenda, making research on options one of the three research cluster to be addressed (next to 'safety task' and 'system knowledge and monitoring').

Adaptation options were clustered to yield strategic alternatives to be implemented progressively, depending on the speed of climate change and in particular sea level rise. This resulted in four possible strategies for the Wadden Region (Delta Commissioner, 2012):

1. *Continuing the current strategy.* Sand replenishments and improving dykes and hydraulic structures;
2. *Prevention plus.* Linking the current prevention strategy to ecological and other objectives and ambitions (e.g. by developing innovative dykes and using natural processes more);
3. *System interventions.* Such as additional replenishments along the North Sea coast if the current or optimised prevention strategy of sand replenishments does not sufficiently counter the Wadden Sea ‘drowning’;
4. *Investments in spatial organisation and disaster management (multi-layer safety).* Preventing casualties and damage in the case of a flood.

Strategy 4 was reintroduced on the adaptation agenda at the explicit request of the Delta Commissioner. Reflecting on the decision trees, we observe that consensus building was not addressed explicitly but considered an implicit result of the appraisal process. Another deviation is that monetary valuation is seen as part of the formal appraisal. In the appraisal the criteria provided by the central Delta Programme were used (including costs). Felt missing from the ATN are decisions towards and methods for the identification and appraisal of criteria that are typical for climate change adaptation, such as flexibility and robustness. The largest deviation from the decision trees that the strategies were appraised qualitatively rather than quantitatively. Time and financial restrictions played a major role in the selection of methods.

*Step 4*

For the next year the Delta Programme report is under preparation. It entails getting to promising strategies. I could reflect on this step using draft documents that are prepared by the sub-programme now as an input and annex to the Delta Programme 2014. These are neither final nor public documents though.

- *Entry point: General problem definition and question/task addressed.*
- *Path through IM and decision trees.*
- *Method applied. Why this method? Theoretical assumptions? What were the strengths and weakness of applying this method?*
- *Results achieved and reflection thereof.*

**Discussion**

We applied the decision trees of the diagnostic framework to the decision-making process in the Delta Programme for the Dutch Wadden Region. We observe that the decision trees explain quite well the path from research questions to methods. They also offer inspiration for the Wadden region, such as to address consensus building explicitly.

Methods that were felt necessary for the Delta Programme and have been developed are:

- An overaching planning method (here Adaptive Delta Management) that outlines the planning process.
- Methods to identify the urgency and the particular consequences of climate change that a decision-making process is responsible for.
- Tools to identify and appraise indicators of particular relevance to climate change adaptation that typical economic valuation tools may under-valuate, e.g. flexibility and robustness.
- Methods to plan the timing of options and combine options into adaptation pathways.
- Methods to identify and deepen our understanding of options or strategic alternatives. Study options first before making the step to compare.
- Development of an evaluation method and criteria. Develop more gradual appreciation of adaptation alternatives by moving from potential to promising, and next preferred alternatives in the course of a number of years, before final selection. Each step allowing for more refinement.

The Delta Programme as well as the diagnostic framework could benefit from:

- Activities to improve transparency and credibility of the work (incl knowledge sharing systems)
- Procedural tools / methods, e.g. how to organise the adaptation governance, to developing a research agenda, select goals and define criteria across different entities in the planning process.

We observe that diversions from the diagnostic framework occur for pragmatic reasons, such as availability of resources and experience of the involved experts. Also strategies can be dropped at an early stage for political reasons rather than formal appraisal criteria. Strategies can also be reintroduced on the adaptation agenda at the explicit intervention of actors. The decision trees do not account for 'power play'. Significantly, in the commissioning of research there is a focus on own knowledge institutes and experts. In other policy implementation processes, open tenders for decision support research have resulted in a new interdisciplinary research community and the creation of new evidence for innovative water safety alternatives (e.g. Werners *et al.*, 2010).

Finally, we feel that the starting point of the decision task navigator 'impact assessment' reflects the more typical process of adaptation planning, which begins with the generation of climate projections, then an analysis of their impacts and finally the design and assessment of options to adapt to those impacts (Dessai *et al.*, 2009). Recent studies have suggested that the process should be inverted and start from the adaptation problem in its decision context in order to satisfy information needs of decision-makers in the face of long-term planning under uncertainty (Cash *et al.*, 2006; Kwadijk *et al.*, 2010; Brown, 2011; Reeder and Ranger, 2011; Hanger *et al.*, 2013). The diagnostic framework may benefit from recent approaches suggested by Haasnoot *et al* (2013), Werners *et al* (2013a) and Reeder *et al* (2011).

**Conclusions**

We observe that the use of methods in the adaptation planning process can be explained quite well by the decision trees of the diagnostic framework. Diversions occur when the selection of tools is informed by practical limitations of the decision making process, such as available resources and experience of the involved experts.

# ADAPTATION TO CLIMATE CHANGE IN THE GUADALQUIVIR BASIN

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*Summary:*



## Agriculture in Andalusia

The agricultural sector in Andalusia still maintains its relative importance when compared. 56.7% of the land in the region is devoted to this activity[18] (87,599 km$^2$), a percentage six points higher than the national reality (50%) and way beyond the European estimate (39%). Likewise, the agricultural sector still maintains its relative importance as a provider of job opportunities in the region, employing 10.2% of the labor force against the 4.3% of Spain as a whole. In fact, the agricultural sector in Andalusia provides nearly 27% of total in national terms. Therefore, agriculture remains as one of the main drivers for regional development in Andalusia, with a clear impact in its economy and social dynamics.

More than half of the arable land in Andalusia is devoted to olive grove and fruit production, mainly citrus fruits. In particular, olive oil production represents 80% of total production in Spain and nearly 25% of world production, representing the most dynamic sector for the Andalusian economy in terms of exports[19]. This distribution of the agricultural land makes the region especially vulnerable to climate change since agricultural production depends mostly on permanent crops.

## Description of the problem under study: options and criteria

Given the importance of agriculture for the local economy and the vulnerability of the sector against climatic variations, the Government of Andalusia initiated its *Strategy against Climate Change*[20] as early as in 2002. This initiative was the first of its kind in Spain. Besides this document, the Government of Andalusia sanctioned on June 5th 2007 the *Andalusian Plan of Action for Climate 2007-2012: Mitigation Plan*. The objective of the program was to reduce 19% of all greenhouse gas emissions in Andalusia by 2012.

[18] Consejería de Agricultura y Pesca (2012)
[19] Consejería de Medio Ambiente (2012)
[20] Estrategia Andaluza ante el Cambio Climático, available at Portal Andaluz del Cambio Climático

On August 3rd 2010, the regional Government sanctioned a new Plan, the Andalusian Climate Change Adaptation Program[21], which aims to minimize the negative effects of climate change in the Andalusian region. The Program is again divided into several interrelated subprograms that set the steps to be followed in a more precise way. These subprograms are:

- **Subprogram 1:** Definition of immediate measures aimed to promote efficient energy use, improve water management, prevent soil erosion and preserve biodiversity.

- **Subprogram 2:** Sector analysis on the effects of climate change, measuring impacts and adaptation measures in the following sectors: water, energy, soil, forests, biodiversity, health, agriculture, tourism sector, transports and land management.

- **Subprogram 3:** Define sector oriented adaptation measures following information generated in previous subprograms. This step resulted in a series of reports[22] developed by Andalusian Government's sectoral offices that contained specific adaptation options for their area of expertise (see summary for Agriculture and Water Sectors in Annex 1)

Drawing from these reports and the specific measures they contain, as well as discussions with selected stakeholders (Director of a Farm Management Firm, Spanish Climate Change office, Environmental Group representative, researchers) the research team started the design of an AHP exercise aimed to prioritize different adaptation options for the agricultural sector in the Guadalquivir basin. Five OPTIONS were identified according to their feasibility and their relevance for the area under study. These were:

- **Option 1: Modernization and improvement of irrigation systems**
  - Improve irrigation techniques as well as water distribution and supply infrastructure maintenance in order to reduce water leaks

- **Option 2: Improving irrigation water management and governance**
  - Control of water consumption. Set detection and fine procedures for non-legal or abusive water use
  - Improve irrigation programming
  - Introduce community irrigation schemes
  - Transparency and public participation in water planning and management

- **Option 3: Setting up a water tariff policy**
  - Measure and charge farmers based on the amount of water truly used

- **Option 4: Crop adaptation**
  - Introduce changes in crop rotation
  - Introduce crop varieties with longer harvesting cycles and more resilient to water scarcity and higher temperatures

[21] Programa Andaluz de Adaptación al Cambio Climático, available at Portal Andaluz del Cambio Climático
[22] These reports are available online at Junta de Andalucia's website

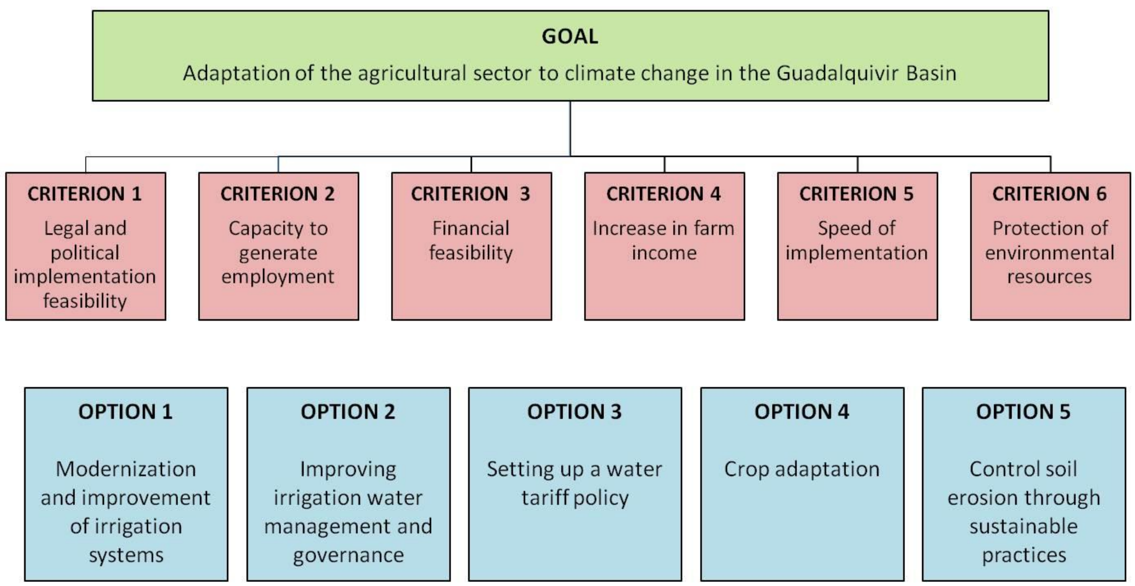
- Redesign pest and disease control systems

- **Option 5: Control soil erosion through sustainable practices**
  - Control soil erosion in more vulnerable areas
  - Promote sustainable agricultural practices

Second, the following CRITERIA were chosen:

- Criterion 1: Legal and political implementation feasibility
- Criterion 2: Capacity to generate employment
- Criterion 3: Financial feasibility
- Criterion 4: Increase in farm income
- Criterion 5: Speed of implementation
- Criterion 6: Protection of environmental resources

As a result of the former exercise, the following Decision Hierarchy was obtained:




The options and criteria used in this AHP exercise are related to a similar exercise undertaken by the research team at the Guadiana river basin. With the intention to provide ground for discussion and share elements with that previous study that allow some level of comparison, the criteria chosen in the Guadalquivir case are exactly the same as the ones used in the Guadiana case. On the other hand, the options chosen differ in a higher extent since both regions specific realities and challenges require particular responses in their process of adaptation to climate change. This diversity is what gives the basis of comparison of the two regions.

## Questionnaire

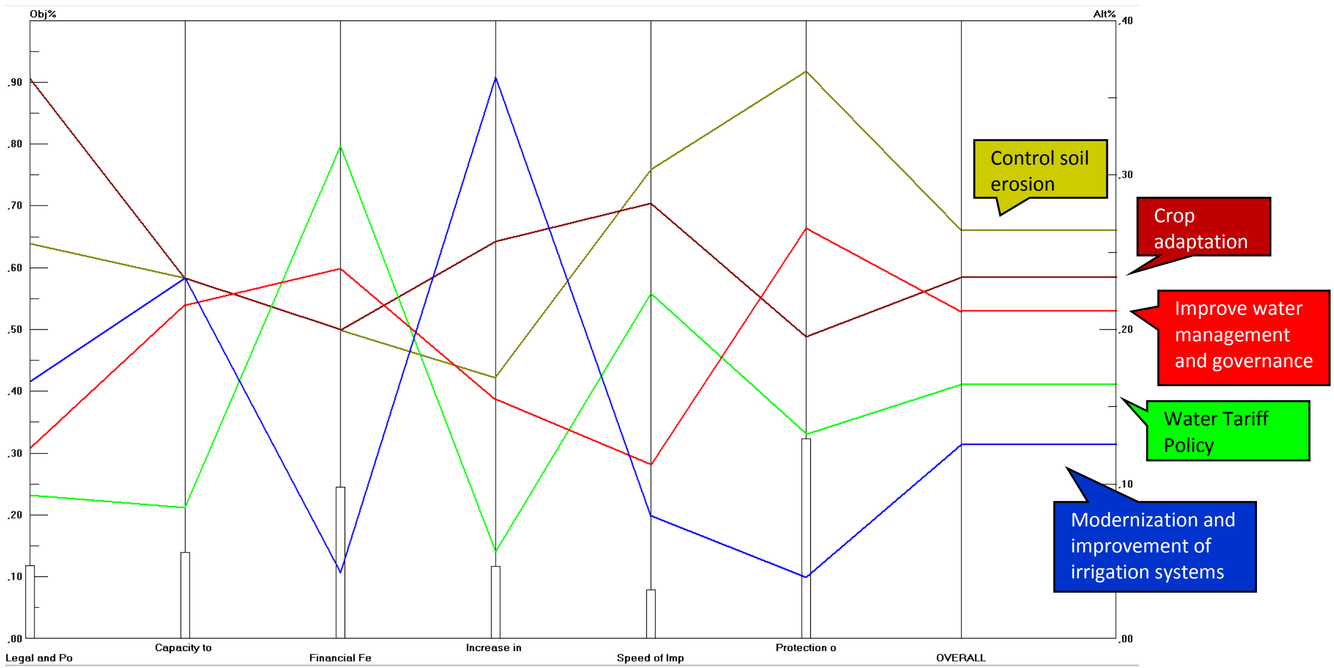
The next step in the development of the AHP exercise was to carry out a pairwise comparison, comparing elements to one another, two at a time, with respect to their impact or importance on an element above them in the hierarchy. In order to fulfill this step and keep a record of the interviews, the research team designed a questionnaire divided in two sections.

First, interviewees are asked to compare the relative preference for each of the measures based on every criterion. For example, for the first criterion, *feasibility of its legal and political implementation*, which refers to the applicability of the chosen measure in relation to the existing legal framework, interviewees have to compare one option against another in relation to their ability to be designed, supported and implemented from the political standpoint. This exercise will be repeated with the rest of the criteria: *capacity to generate employment; financial feasibility; increase of farm income; speed of implementation; and protection of environmental resources*.

Second, interviewees are asked to assess the relative importance of the criteria with regard to the achievement of the goal. That is, they will need to compare the relative importance of each of the above criteria with respect to their importance in the *prioritization of adaptation options for the agriculture sector in the Guadalquivir Basin*.

## Results from pilot interviews using Expert Choice software

The research team undertook four preliminary interviews in order to refine the questionnaire and become familiar with the use of the software package used for the development of the exercise. Following, the interviews were expanded to a larger audience of selected stakeholders (managers of Farm Management Firm, Farmers, Spanish Climate Change office, Environmental Groups, Academics, irrigation association) . These interviews provided the following results:




We observe how the results from the questionnaire are sporadic, with little preference for one particular option across the six criteria. However, what can be concluded is that modernization of the irrigation system can be considered the least preferred, of the five options available. This may be due to the lack of perceived financial feasibility of this option, the speed of implementation and the lack of protection for environmental resources. Despite this, what should be noted is this option is perceived to be the most successful for increasing individual farm incomes. In contrast, the preferred option is that of reduction of soil erosion through sustainable practices. This appears to be especially attractive due to the protection of environmental resources and the potential speed of implementation. It should duly be considered that this option is perceived only to be the third most effective in contributing to increased farm incomes.

Comparing these results with those obtained in the Guadiana basin, it is worth mentioning that water supply-enhancing hard measures, such as the construction lf large dams, are inexistent in the Guadalquivir. This is due to the fact that the Guadalquivir basin is already regulated near its full capacity (closed basin). In this basin, the hard measures are only related to the modernization and improvement of irrigation systems, which is the least preferred option. Along the same line, the supply-enhancing hard measure of constructions of dams and reservoirs in the Guadiana basin is the least preferred option. In the Guadalquivir basin, demand-side soft measures, such as the application of water tariffs, appear as an important CCA option, which reflects a more developed water institution in the Guadalquivir. With respect to the crop adaptation measures to reduce climate change impacts, the Guadalquivir basin shows more detailed options and environmental concern. In fact, along changes in cropping patters to adapt to climate change, the Andalucía CCA plan, considers the reduction of soil erosion (through changes in tillage operations) a key adaptation measure. This measure is the preferred option in the AHP results in the Guadalquivir basin.

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ANNEX 1:

**Adaptation measures for the agricultural and water resources sectors obtained in Andalusia obtained from the Andalusia Strategy against Climate Change**

| **Agriculture** |
|---|
| 1. Design of adequate irrigation systems |
| 2. Strategies in crop adaptation:<br>a. Introduce changes in crop rotation<br>b. Introduce crop varieties with longer harvesting cycles and more resilient to water scarcity and higher temperatures<br>c. Redesign pest and disease control systems |
| 3. Set up an indicator system that analyzes the evolution of the agricultural sector in relationship to climate change |
| 4. Design training programs for farmers aimed to put into practice climate change adaptation techniques |
| 5. Design incentive systems that reward sustainable farming techniques and those which consider the adoption of basic adaptation measures in the agricultural sector |
| 6. Promote energy crops in the coordination framework between GHG mitigation and adaptation policies |
| 7. Control soil erosion in more vulnerable areas |

| **Water resources** |
|---|
| 1. Promote reforestation projects to increase available water resources |
| 2. Introduce rainwater collection systems |
| 3. Seawater desalination |
| 4. Recycle treated waste water |
| 5. Introduce measures aimed at reducing urban water demand |
| 6. Set up a water tariff policy |
| 7. Introduce measures aimed at reducing water demand from irrigated lands:<br>a. Measure and charge farmers based on the amount of water truly used<br>b. Design, manage and preserve irrigation systems adequately<br>c. Train irrigators in new technologies and sustainable development techniques with regard to climate change |

| |
|---|
| 8. Control water consumption in industrial installations |
| 9. Introduce tools and techniques to improve water resource management |
| 10. Development of early drought detection methods |
| 11. Creation of reaction plans against extreme hydrological events |
| 12. Promote the installation of water collection and storage systems in office buildings and houses for non-consumptive uses |
| 13. Improve water distribution and supply infrastructure maintenance in order to reduce water leaks |

## APPENDIX II: THE TYPOLOGY OF METHODS AND METRICS

| Type of approaches | Method (level 1) | Method (level 2) | Method (level 3) | Method (level 4) | Tools |
|---|---|---|---|---|---|
| Participation and engagement | | | | | |
| | Tools for understanding complexity | | | | |
| | Participatory analysis tools | | | | |
| | Stakeholder engagement and analysis tools | | | | Socio-inst. Network mapping |
| | Community based and participatory toolkits | | | | |
| | Large group and whole system techniques | | | | |
| | Conflict resolution techniques | | | | |
| | Facilitation toolkits | | | | |
| Impact analysis | | | | | |
| | Describing current impacts | | | | |
| | | Trend detection (via statistical methods) | | | |
| | | | | | GODAS |
| | | | | | RClimDex |
| | | Impact attribution | | | |
| | | | Single-Step Attribution to External Forcings | | |
| | | | Multi-Step Attribution to External Forcings | | |
| | | | Associative Pattern Attribution to External Forcing | | |
| | | | Attribution to a Change in Climatic Conditions (Climate Change) | | |
| | Modelling future impacts | | | | |
| | | Model-based projections | | | |

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| | | | Biophysical models | | |
| | | | | Agricultural models | |
| | | | | | APSIM, the agricultural production systems simulator |
| | | | | | DSSAT, Decision Support System for Agrotechnology Transfer |
| | | | | | GRAZPLAN, four models to support decisions for grazing systems |
| | | | | | Community Land Model |
| | | | | | COSMO CLM |
| | | | | | Grapevine Growth Model |
| | | | | | Aquacrop |
| | | | | Water resource models | |
| | | | | | WEAP, a water evaluation and planning system |
| | | | | | RiverWare, a general river and reservoir modeling tool |
| | | | | | WaterGap, Water - a Global Analysis and Prognosis |
| | | | | | LISFLOOD |
| | | | | | |
| | | | | | VIC |
| | | | | Biodiversity models | |
| | | | | | GLOBIO3, a global biodiversity assessment model |
| | | | | | LPJmL, Lund-Potsdam-Jena managed Land Dynamic Global Vegetation and Water Balance Model |
| | | | | | Bioclimactic Envelope Modeling |

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|---|---|---|---|---|---|
| | | | | Coastal zone models | |
| | | | | | DIVA, Dynamic Interactive Vulnerability Assessment, is an |
| | | | | | Roadmap, Roadmap for Adapting to Coastal Risk |
| | | | | Multi-sector models | |
| | | | | | SimClim, the Simulator of Climate Change Risks and Adaptation Initiatives |
| | | | | | CLIMSAVE IA, Integrated Assessment Platform for impacts, adaptation and vulnerability in Europe |
| | | | | | CIAS, Community Integrated Assessment System, a system of linked energy, climate, impacts and economic models |
| | | | | | Regional Atmospheric Modeling System |
| | | | Modelling of socio-economic impacts | | |
| | | | | Economic Integrated Assessment Models (IAM) | |
| | | | | Investment and Financial Flows (I&FF) | |
| | | | | Computable General Equilibrium models (GCE) | |
| | | | | Impact assessment (scenario based assessment) | |
| | | | | Impact assessment - shocks | |

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|---|---|---|---|---|---|
| | | | | Impact assessment - econometric based | |
| | | | | Risk management | |
| | | | | | CATSIM |
| | | | | Adaptation assessments | |
| | | | | | |
| | | | | | Mortality-temperature models |
| | | | | | Economic impact analysis |
| | | | | | Economic optimization |
| | | | Model-based integrated analysis | | |
| | | | | Multi-sector models | |
| | | | | | A-TEAM, Advanced Terrestrial Ecosystem Analysis and Modelling |
| | | | | | RegIS, Regional Climate Change Impact and Response Studies in East Anglia and North West England |
| | | | | | CIAS, Community Integrated Assessment System, a system of linked energy, climate, impacts and economic models |
| | | Vulnerability indication | | | |
| | | | Vulnerability indices | | |
| | | | | | BACLIAT |
| | | | | Global vulnerability indices | |
| | | | | | Global Adaptation Index |
| | | | | | World Risk Index |
| | | | | | Climate Vulnerability Monitor |
| | | | Starting point vulnerability | | |
| | | | | Agent-based | |

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|---|---|---|---|---|---|
| | | | | modelling | |
| | | | | Household survey | |
| | | | | Ethnographic data on multiple stresses | |
| | | | | Post-disaster assessments | |
| | | | | Integrated assessment community mapping and multivariate probit approach | |
| | | | | Multiscalar-indicators and downscaled scenarios at local level | |
| | | | | Analysis of historical data and qualitiative interviews | |
| | | Participatory methods of vulnerability assessment | | | |
| | | | Community vulnerability assessment | | |
| | | | | Capacities and Vulnerability Analysis (CVA) | |
| | | | | Vulnerability and Capacity Assessment (VCA) | |
| | | | | | Community Vulnerability and Capacity Assessment (CVCA) process |

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|---|---|---|---|---|---|
| | | | | | CRiSTAL (Community-based Risk Screening Tool – Adaptation and Livelihoods) |
| | | | | Participatory Rural Appraisal (PRA) | |
| | | | | | |
| | | | Expert judgement | | |
| | | | Participatory scenario development | | |
| | | | User-controlled learning tools | | |
| | | | | User-driven indicator mapping | |
| | | | | | CARAVAN vulnerability mapping tool |
| Capacity analysis | | | | | |
| | Indicators of adaptive capacity | | | | |
| | Participatory Vulnerability and Capacity Assessments | | | | |
| | Organizational adaptive capacity | | | | |
| Behavioural analysis | | | | | |
| | Social psychological | | | | |
| | Utility maximisation | | | | |
| | Bounded rationality | | | | |
| Institutional analysis | | | | | |
| | Governance description | | | | |
| | Governance design | | | | |
| | Governance emergence | | | | |
| | | Anthropology and political ecology | | | |
| | | New institutional economics | | | |
| Decision-making | | | | | |
| | Informal decision making | | | | |

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|---|---|---|---|---|---|
| | Formal decision-analysis | | | | |
| | | CBA | CBA | | |
| | | CEA | CEA | | |
| | | MCA | | | |
| | | | | | Adaptation decision matrix |
| | | Robust decision-making | Robust decision-making | | |
| | | Real option analysis | Real options analysis | | |
| | | Adaptive management | | | |
| Planning and implementation | | | | | |
| | | | | | Zonation |
| | Elements of a participatory planning and implementation process | | | | |
| | Tools for scoping the plan | | | | Tool for Environmental Assessment and Management |
| | | | | | Screening of Adaptation options |
| | Planning tools | | | | |
| | | | | | M-CACES |
| Monitoring and evaluation | | | | | |
| | Frameworks for evaluation of adaptation | | | | |
| | Common Evaluation Methods | | | | |
| | Community based evaluation approaches | | | | |
| | Frameworks for evaluation of participation and engagement | | | | |
| | Participatory evaluation tools | | | | |
| | Evaluation as an opportunity for learning | | | | |
| Learning and reflection | | | | | |
| | Learning Loops | | | | |
| | Evolution and confidence and emotional aspects of learning | | | | |

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|---|---|---|---|---|---|
| | Reflection and noticing | | | | |
| | Relational aspects | | | | |
| | Tools | | | | |
| Valuation | | | | | |
| | Non-market outcomes | | | | |
| | Indirect outcomes | | | | |
| | Inter-temporal outcomes | | | | |
| | Uncertain outcomes | | | | |
| Scenario analysis | | | | | |
| | Qualitative information | | | | |
| | Quantified variables and their sources | | | | |
| | Characterising future climate | | | | |
| | | | | | The Climate Impacts LINK Project |
| | | Sensitivity analysis | | | |
| | | Climate analogues | | | |
| | | Trend extrapolation | | | |
| | | "Delta" change | | | |
| | | Pattern-scaling | | | |
| | | Stochastic weather generation | | | |
| | | Empirical/statistical downscaling | | | Statistical DownScaling Model (SDSM) |
| | | Dynamical downscaling (RCM) | | | |
| | | | | | COSMIC2 |
| | | | | | PRECIS |
| | | Coupled AOGCMs | | | |
| | | Probabilistic | | | |
| | Characterising other environmental and socio-economic futures | | | | |
| | | Atmospheric composition scenarios | | | |

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|---|---|---|---|---|---|
| | | Sea-level scenarios | | | MAGICC/SCENGEN |
| | | Socio-economic scenarios | | | UNDP Scenario Guidance |
| | | Land-use scenarios | | | |
| | | Technology scenarios | | | |
| | | Adaptation scenarios | | | |
| | | | | | PEP |
| | Scenarios as integrating devices | | | | |
| | | Global scenario distribution portals | | | |
| | | | | | IPCC Data Distribution Centre |
| | | | | | The World Bank Climate Change Data Portal |
| | | | | | UNDP Climate Change Country Profiles |
| | | Continental/regional scenario distribution portals | | | |
| | | | | | Africa: Climate Information Portal |
| | | | | | Asia and the Pacific: Climate Change Adaptation in Asia and the Pacific |
| | | | | | Europe: The European Climate Adaptation Platform, CLIMATE-ADAPT |
| | | | | | Caribbean: The Caribbean Community Climate Change Centre |
| | | | | | Central America: The SERVE project for Mesoamerica |
| | | National scenario distribution portals | | | |
| | | | | | Australia: OzClim |
| | | | | | Canada: Canadian Climate Change Scenarios Network |
| | | | | | Canada: Ouranus |
| | | | | | Denmark: Climate Change Adaptation portal |
| | | | | | Finland: Climateguide.fi |

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|---|---|---|---|---|---|
| | | | | | Germany: KomPass (Kompetenzzentrum, Klimafolgen und Anpassung) |
| | | | | | Germany: Climate Service Center – Germany |
| | | | | | Netherlands: Platform Communication on Climate Change (PCCC) |
| | | | | | Norway: Norwegian Climate Change Adaptation Programme web portal |
| | | | | | Spain: State Meteorological Agency of Spain |
| | | | | | United Kingdom: UK Climate Impacts Programme (UKCIP) |
| | | | | | USA: Nature Conservancy Climate Wizard |
| | | Sub-national scenario distribution portals | | | |
| | | | | | US Pacific Northwest: Climate Impacts Group |
| Treatment of uncertainty | | | | | |
| | Sources of uncertainty | | | | |
| | | | | | PEP |
| | | Expert consultation | | | |
| | | Identification by experts for each key factor | | | |
| | | Literature review | | | |
| | Calibrating uncertainty | | | | |
| | | Quantitatively | | | |
| | | | Statistical analysis | | |
| | | | Modelling | | |
| | | | Expert elicitation | | |
| | | Qualitatively | | | |
| | | | Expert judgement | | |
| | Communicating uncertainty | | | | |
| | | | | | CARAVAN vulnerability mapping tool |

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|---|---|---|---|---|---|
| | | Matching the message, the messenger and the audience (avoiding cognitive dissonance) | | | |

# APPENDIX III: INDIVIDUAL TOOLBOX ENTRIES

## Simplified Standalone Fire Model

**Description**

The simplified stand-alone fire model (SFM) is a model based on the fire routine implemented in the Community Land Model (Kloster et al., 2010) (Link to the other CLM entry in the toolbox), which exploits the outputs of CLM, was developed to test the impacts of different adaptation options. SFM-C provides faster computing time at the cost of losing the fire feedbacks to the biophysical part of the model.

Within the framework of the SFM algorithm two adaptation options strategies are currently implemented: 1) modelling of active suppression and 2) prescribed burnings

**Applicability**

The SFM might be used to simulate future patterns of fires probability and burned area, as well as for the analysis of the impacts of prescribed burning and enhancement of fires suppressions at pan-European scale.

**Accessibility**

It is recommended to contact the researchers involved with developing the model:

Nikolay Khabarov of the International Institute for Applied Systems Analysis (khabarov@iiasa.ac.at)

**Strengths and Weaknesses**

Strengths:

- High flexibility for testing adaptation options
- Low computational complexity
- Adaptation options included in the modeling framework

Weaknesses

- Less precise description of the interactions between fuel availability and fires

**References**

Kloster, Silvia, Natalie M. Mahowald, James T. Randerson, Peter E. Thornton, Forrest M. Hoffman, Samuel Levis, Peter J. Lawrence, Johannes J. Feddema, Keith W. Oleson, and David M. Lawrence. 2010. “Fire Dynamics During the 20th Century Simulated by the Community Land Model.” Biogeosciences 7 (6): 1877–1902.

## The CARAVAN Tool

### Description

The CARAVAN (Climate change: a regional assessment of vulnerability and adaptive capacity for the Nordic countries) vulnerability mapping tool is an online resource designed to help users explore different aspects of vulnerability to climate change in the Nordic region. Indicators of exposure to climate change, the sensitivity to these changes and the adaptive capacity to cope with these changes are captured in a geographically detailed web-based tool that allows interactive mapping of combinations of indicators into indices of vulnerability. The tool is designed to allow users to explore these aspects (e.g. by selecting indicators of interest, mapping them alone, weighting them, combining them, and/or looking at them in conjunction with exposure indicators under different climate scenarios), rather than predefining the factors that influence vulnerability. The vulnerability mapping tool covers to two themes, vulnerability of the elderly and agriculture, and is available at: www.iav-mapping.net/CARAVAN.

### Applications

CARAVAN was developed and utilized for a project of the same name from 2008 to 2010 to assess different ways to estimate and map vulnerability to climate change at municipal scales in the Nordic region, specifically Finland, Norway, and Sweden. It was also used as a key component of the Nordic Elderly case of the MEDIAITON project, and more information can be found on the MEDIATION website.

### Accessibility

The CARAVAN tool is publicly accessible via the website:

http://www.iav-mapping.net/CARAVAN/CARAVAN.html

### References and Further Reading

http://www.iav-mapping.net/CARAVAN/CARAVAN.html

http://mediation-project.eu/case-studies/northern-europe-vulnerability-of-the-elderly-to-climate-change-in-the-nordic-region

## Analytic Hierarchy Process (AHP)

**Description**

Analytic Hierarchy Process (AHP) is a type of multi-criteria assessment (MCA) technique for analyzing complex decisions. It was developed in the early 1980s to help decision-makers find the option that best suits their goal and understanding of the 'problem'. Nowadays it is applied in a wide variety of fields (mainly engineering, business strategic management, education, quality assessment).

The method is used to compare a set of options by using participants data, experience and judgment, and converting these into numerical values. It allows them to compare in a rational and consistent way diverse elements that are often difficult to measure (AHP measures intangibles in relative terms).

It evaluates various elements by comparing them to one another two at a time (pairwise comparison). Comparisons are made using a scale of 'absolute judgements' that represents how much more one element dominates another with respect to a given reference point.

AHP is very flexible and can be adapted to different needs and contexts. Criteria (or attributes) can be decided in advance or through a participatory process (increase transparency and dialogue). Criteria can be tangible and intangible, can have subcriteria and be as many as necessary. The process can involve as many participants as required. The number of alternatives to evaluate can also vary.

**Strengths and Weaknesses**

Results change as new options/ alternatives are considered in the analysis. However, some criteria are not independent so this can bias or complicate the way in which they are assessed (clusters can be formed). Also, AHP can become complicated if lots of criteria and options are considered.

The AHP method is used in a variety of problem domains; it is widely used and is published in many studies and research papers. It is technically valid and practically useful. It can promote discussion among participants and capture different points of view. It can compare tangibles and intangibles. To compensate for drawbacks, it can be used in combination with other (objective and subjective) methods.

**Applications**

Information on applications of AHP can be found at the WeAdapt.org website:

http://weadapt.org/knowledge-base/adaptation-training/module-ahp

AHP can be carried out with paper and pen however to assist with application of the method, a software tool has been developed as part of the Climate Adaptation Options eXplorer, or ADx.

**Accessibility**

AHP is being used in several adaptation studies in different EU countries as part of the Mediation project. The method does not seem to need any particular modification for use in adaptation projects but (as always) users need to be aware of the conditions of applicability of the method.

**References and Further Reading**

Recommended reading: The Analytic Hierarchy Process for Decisions in a Complex World (Thomas Saaty 1982, revised ed. 2000)

http://weadapt.org/knowledge-base/adaptation-training/module-ahp

## PACT

### Description

The PACT tool gives organisations a detailed analysis of their capacity to take climate resilient decisions as well as guidance on their optimum next steps to improve that capacity (there is also a PACT tool for climate change mitigation). This guidance takes the form of a tailored action plan to develop the organisation's capacity that builds upon what they already do well.

PACT can be used for many purposes, ranging from reviews of single organisations to multiple organisations that form a system of organisations. Those organisations who complete an online PACT inquiry receive a tailored roadmap showing how they can move directly from assessing the status of their climate change programme to planning improvements in it.

What does it do?

- Provides a benchmark of an organisations progress on addressing current and future climate change.
- Helps organisations understand the challenge they face, and the level of capacity needed to address it.
- Shows organisations how to improve their approach to addressing climate change.
- Uses what an organisation already does well as a foundation on which to develop new approaches.
- Uses the benchmark to monitor progress against (informing progress reports to relevant internal and external stakeholders)

### Strengths and Weaknesses

*Strengths:*

PACT provides organisations with a comprehensive benchmark of their adaptive capacity and a detailed description of their next steps to develop that capacity. The online tool allows this to be done quickly, efficiently, and at comparatively low cost. The benchmark of capacity can be used for monitoring progress and reporting internally and externally. The PACT Action Plan defines an innovative plan of action. PACT dissects an organisations climate change capacity challenge into manageable chunks, and has been independently reviewed by UKCIP as being the most comprehensive tool in measuring and developing adaptive capacity.

*Weaknesses:*

PACT informs organisations what needs to be done, it cannot define exactly how they should do it for every circumstance. The Alexander Ballard debrief is therefore highly recommended in order to assist with translating it into specific circumstances.

### Applications

It is only at the point of making decisions that organisations can decide to do things differently. The capacity of organisations to make climate resilient decisions remains scarce. Yet organisations, by their very nature, are responsible for some of the largest climate vulnerable decisions that there are. Most organisations will be vulnerable in some way or another. In an effort to support climate resilient decision-making there is a growing and vast quantity of information about climate change and climate impacts, and the types of technology and options available to address them. This valuable information and associated technologies are essential parts of the solution. However, PACT recognises that the availability of information and technology does not necessarily lead to raised awareness about the agenda and how to tackle it. Likewise, even if awareness is raised, it does not necessary lead to any meaningful action. PACT provides organisations with a route map on how to use information to raise awareness that leads to meaningful actions that apply appropriate technologies accordingly. PACT helps organisations design strategies that will lead to the changes they need to make in order to make climate resilient decisions.

**Accessibility**

Organisations log-in to an online interactive PACT Inquiry. They are then asked questions about how climate change information is used and managed in their organisation, paying specific attention to nine key complementary organisational capacities critical for climate resilient decision-making: awareness, agency; leadership, agents of change; working together; learning; operational management; programme scope & coherence; and expertise.

The interactive inquiry tailors its questioning based upon the answers being given. This ensures that the questions being asked remain relevant and meaningful to the particular organisation completing the inquiry.

Once the PACT inquiry has been processed by experts, the results provide each organisation with an understanding of the level of climate adaptation capacity the organisation has (i.e. 'adaptive capacity'), and what capacity it needs. If there is a gap between these two positions (which there almost always is) PACT provides a detailed description of the capacity development challenge the organisation faces, and the optimum next steps to address that gap. PACT is able to do this for organisations that are just starting out on the agenda right through to those who are leading the way.

Organisations who have completed a PACT Inquiry receive a PACT Summary Report, outlining their challenge (aimed at top team / board level discussion), and a PACT Action Plan, detailing the actions they are doing well, those they are partially doing, those that are planned, and those that are not implemented yet but need to be (aimed at delivery management level). These reports are combined with a debrief of the results, the reports, and what they mean for the organisation from one of Alexander Ballard Ltd's PACT experts. This gives an organisation not just a map of their path to climate resilience but teaches them how to read it.

**References and Further Reading**


http://www.alexanderballard.co.uk/

http://www.pact.co/

http://weadapt.org/knowledge-base/adaptation-training/module-pact

## Socio-Institutional Network Mapping

### Description

There is an increasing body of research on the role of socio-institutional networks in climate adaptation. The varying definitions of the term 'social network' reflect its conceptual and methodological development initially in mathematics (graph theory) and sociology, and more recently in environmental sustainability and related interdisciplinary areas, particularly climate change adaptation and resilience of social-ecological systems.

This research all focuses on human or organizational actors and their social relationships, and connections among units and between actors. For the purposes here, 'social network' is used to refer to institutional actors and the linkages among these, as well as other actors (individuals, organizations, interest groups etc.). It relates to the analysis of governance and decision-making networks, which are close to the concepts of policy and governance networks (e.g. Blanco et al. 2011). By including multiple types of actors it recognizes that informal ties as well as formal ones are deeply involved in 'governance' (e.g. see Pelling et al. 2008).

Berkhout et al., (2006) found that many of the resources required for carrying out the process of adaptation lie outside the boundary of a particular organization. As a result, inter-relationships between organisations are influential in determining how (and if) adaptation processes will occur. Following from this, it is important to identify the existing socio-institutional landscape and feedback processes in climate adaptation research, to speed up the necessary 'climate-adapted routines and capability to be developed' (Berkhout et al., 2006).

Against this background, a number of methods are emerging that can identify the various stakeholders involved in adaptation decisions, and map out their linkages. These can be represented (visually) and analyzed with network maps. These can be further analysed, in qualitative or quantitative terms using social network analysis to provide additional information The background and key benefits of the approach are provided in Box 1.

Participatory social network mapping and analysis is able to reveal insights about the substance of these relationships by making explicit the types of flows between actors (e.g. information, money, advice, policy, etc) and the perceptions of influence and power in the network. Quantitative SNA provides a variety of measures/indicators to help describe the overall relational structure of a social system, as well as the roles of individuals within it.

It can provide insights which can then be explored further with other methods – follow-up interviews, statistical analysis, agent-based modelling, etc.

The main difference between qualitative and quantitative social network analysis are that quantitative SNA graphs are 'whole' networks rather than ego-centric networks based on the perception of (usually) just one actor.

They are also much more comprehensive (i.e. with more nodes and links) and can be quantitatively analysed with SNA software using standard statistical tests.

### Quantitative Social Network Analysis

Quantitative SNA aims at capturing the entire relevant network. The steps for quantitative social network analysis are:

- Clarifying objectives and defining the scope of analysis (e.g. mapping a knowledge domain).
- Developing a survey methodology and designing the questionnaire.
- Identifying the participants (network) and providing justification for boundaries (if appropriate).
- Collecting survey data and gathering further information from other resources.
- Analyzing the data through formal methods.
- Reviewing process and outcomes to identify problems/opportunities.
- Designing and implementing actions to bring about desired changes.
- Mapping the network again after an appropriate period of time.

This is a resource intensive task, and field research requires very high response rates, and high resources, as any missing data can weaken the analysis. Other approaches using existing data (e.g. co-citation networks, online databases, householder surveys) can also be considered, though it is not always easy to extract relational information or perform suitable data transformations.

**Qualitative Social Network Analysis**

Qualitative social network analysis or social network mapping (SNM) takes advantage of the early steps above - the interviews, surveys or focus group discussions - to elicit information on the relevant networks.

It can facilitate rich discussions, shared understanding and increased awareness between different stakeholders. This can be part of a rapid appraisal before detailed analysis begins. It can also identify entry points for policy influence (Turnpenny et al., 2005) and other 'flows' of resources which can include 'informal capital'.

A number of approaches and tools can be used for network analysis. Following Schiffer (2010), the NetMap guidance is a useful example for applying the approach in a participatory way. The method is usually applied using flipcharts, post-it notes and flat counters with a group of stakeholders who are split into homogeneous groups related to the type of institution they belong to e.g. Government level representatives, NGOs, farmers, etc.

Once the adaptation research question is well defined, participants go through the mapping exercise including an analysis of the network, and then come back into plenary for a discussion of the different networks from the different stakeholder perspectives. This enables a better 'shared understanding' of differing world views. The steps for participatory social network analysis (Schiffer, 2010) are:

• Identifying the question for the analysis.

• Define goals for each actor and note these on each post-it. Allow for multiple goals where appropriate, by noting more than one goal next to the actor (to understand conflicts and synergies).

• The resulting maps allow the participants to discuss the following questions in their groups and produce an in-depth analysis of the decision-making landscape.

• Come back together as a group to discuss the analysis of the results and compare perceptions of strengths, weaknesses, areas of influence and so on. This can promote a shared understanding of the issue and consensus on areas for action.

A range of software existing for both quantitative and qualitative SNA.  This includes software for visualisation and analysis e.g. GEPHI, UCInet, ORA, Netdraw, ORA, etc.

**Strengths and Weaknesses**

| | | |
|---|---|---|
| **Socio-institutional network mapping (Quantitative approaches)** | • **Can provide measures**<br>• **A range of software is available for visualization and analysis e.g. GEPHI, UCInet, ORA** | • **Large sample size needed, or ego-centric partial networks**<br>• **Tends to focus on methodology and technical issues rather than on hypotheses and theories**<br>• **Over-interpretation of results**<br>• **Some authors have questioned an assumed confidence in the measures to characterize the networks**<br>• **Data are often difficult and expensive to obtain, and empirical studies are often quite small. This means it is hard to use data for exploration of alternative measurement strategies.** |
| **Socio-institutional network mapping (Qualitative approaches)** | • Can be done in a day<br>• Encourages participation across diverse viewpoints and actors<br>• Does not prescribe a particular classification of jargon<br>• Yields insights that would be difficult to get any other way<br>• Range of software available for visualization and analysis e.g. Netdraw, UCInet, ORA, but can also remain hand drawn maps | • Can be difficult to integrate different perspectives to produce cohesive maps of whole networks, especially where multiple scales are involved<br>• Some links are less reliably attributed - information is incomplete<br>• Can be difficult to bring together actors that have different perspectives; this can cause tensions, which in turn can bias the results<br>• Results are highly dependent on which actors are involved in the exercise and which actors are not (high subjectivity). Therefore, it is important to ensure actor type representativeness when implementing SNM.<br>• One full day can be too long for some actors to participate. Poor participation of key actors can bias the results. |
| **Socio-institutional network mapping (both approaches)** | • Can generate an understanding of prevailing socio-institutional structures (based on how the actors themselves report them), relating a characterization of the individual actors connectivity, to its local network context, and to the overall whole-network features | • Subjective bias and can be difficult to generalize<br>• Time-consuming, intensive process<br>• Do not have a temporal or spatial dimension<br>• Networks have artificial boundaries (often necessarily)<br>• Design of process is critical to get as many differing viewpoints as possible |

**Applications**

The recognition of social network analysis, and the role of socio-institutional networks in climate adaptation is increasing, reflecting the growing viewpoint that adaptation is a socio-institutional process. The IPCC Special Report on Extreme Events (SREX) (2012) recognises this, in defining adaptation as a process of adjustment to the actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities.

This process-based understanding requires a 'mapping' of the problem framing and actors and thus SNA has a high relevance for adaptation.

To understand the basic elements that constitute a network analysis (both qualitative and quantitative) and how these characteristics can relate specifically to the issue of climate change adaptation it is important to consider network topologies, outlined in the box.

An added complexity with the application of SNA to adaptation is the dynamic nature of climate change. The socio-institutional networks and relationships between the actors (and with their actions) will evolve over time. It is also necessary to consider the differences in decision framing and the links to uncertainty. This includes four common levels of decision framing:

• The architecture of stakeholders and knowledge, and the boundaries involved;

• The defined decision boundaries, i.e. what is in scope;

• Decision making, i.e. the methods, tools and metrics.

• Implementation, and the link to responsibility towards action.

Information on these aspects allows analysis of the value of information in making a decision.

**Accessibility**

The review and case studies provide a number of practical lessons on the application of social network analysis to adaptation. They provide useful information on the types of adaptation problem types where SNA might be appropriate, as well as data needs, resource requirements and good practice.

The application of the qualitative approach is very broad, and can be applied to most adaptation settings. The approach can be useful for adaptation planning, decision-framing, uncertainty and the links to choices of tools.

The quantitative approach provides important additional context for progressing towards adaptation implementation, though there is a need for balanced representation (i.e. of participants) to avoid subjectivity influencing results. The quantitative approach can provide a more detailed analysis, providing correlations, but there is a need for high sample sizes, thus the added time and resources limit the approach to more specific applications (as in the case of the Finnish case study, aligning to an existing survey).

Finally, the Mediation case studies provide some useful messages on the lessons from the application of the approach, outlined below.

1. Barriers to adaptation are part of socio-institutional processes and can potentially be revealed and negotiated through social network analysis.

2. Capacity to adapt is capacity to act in socio-institutional processes, i.e. flows alone are not an indicator of adaptive capacity per se since there can be an imbalance of power which diminishes capacity.

3. The drivers or determinants of adaptive capacity are far more than the availability of information and finance (flows).

4. Adaptive networks can be described formally and this can also help us to identify what outcomes different network configurations may produce.

5. Descriptions of both actors and networks can be related to qualitative metrics and used to benchmark progress towards outcomes.

6. Transformations in adaptive capacity are changes in actor-networks (e.g. new institutional arrangements, new entities or new roles and responsibilities).

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## Economic Optimisation

### Description

The economic optimization model is a single-year mathematical programming model of constrained optimization which represents farmers' behaviour and predicts their response to policy and environmental changes. This model is based on the economic theory-based assumption that farmers maximize their utility subject to economic, technical and policy constraints. The model considers utility losses due to the risk faced by farmers as a response to climate and market variability. It is based on previous work conducted by UPM team (see Blanco, 2010; Esteve, 2009; Varela-Ortega et al., 1998; Varela-Ortega et al., 2006; Varela-Ortega and Blanco, 2008; Varela-Ortega et al., 2008; ) adding the potential simulation of climate change adaptation strategies that farmers will follow in addition to other policy and climate scenarios. The model is written in GAMS and it is calibrated using the risk aversion coefficient according to ranges established by Hazell and Norton (1986).

The objective function is defined as follows:

$$MaxU = Z - \phi * \sigma$$

$$Z = \sum_{c=1}^{n}\sum_{k=1}^{m}\sum_{r=1}^{q} GM_{ckr} * X_{ckr} + \sum_{c=1}^{n}\sum_{k=1}^{m}\sum_{r=1}^{q} SUBS_{cr} * X_{ckr} - IRRC - LABC$$

*Where: Z*: farm income; *Φ*: farmer's risk aversion coefficient; *σ*: standard deviation of farm income; *GM*: gross margin; $X_{c,k,r}$: vector of the activities; *c*: crop; *k*: soil type; *r*: irrigation method; $SUBS_{c,r}$: CAP subsidies; *IRRC*: irrigation costs; *LABC*: labour costs.

This maximization is subject to land, labour, water and policy constraints:

$$g(x) \in S_1 \quad ; \quad x \in S_2$$

This model allows simulating different stakeholder-driven and policy-driven scenarios, to assess their impacts on the environment, on farmers' income, on public expenditure and on land use at farm and at regional level.

The model has been developed, calibrated and validated for the Upper and Medium Guadiana sub-basins in the context of the NeWater and the SCENES projects (Blanco-Gutiérrez et al, 2011; Blanco-Gutiérrez et al., in press; Carmona, 2011; Carmona et al., 2011; Varela-Ortega et al 2011).

### Strengths and Weaknesses

| Key strengths | Potential weaknesses |
|---|---|
| Based on neoclassical theory<br>Widely used to reproduce the farmers' behaviour and to calculate the impacts of given scenarios<br>Powerful solver (GAMS) | Permanent crops are assumed to already be in full production<br>Farmers are presumed to be financially solvent<br>Can suffer from aggregation bias when |

| | |
|---|---|
| | employing regional-level data |

**Applications**

The economic model allows for assessing impacts of climate change and to simulate different policy measures for adaptation, its economic impacts at farm and regional level, its impact on resources consumption and its cost-effectiveness.

Geographic applicability of the tool is limited to local (farm level) and sub-national scales.

The results of the economic model can be used for cost-effectiveness analysis of policy alternatives, as well as economic vulnerability assessment, when combined with social and environmental factors.

**Accessibility**

While no specific documentation exists for this tool; documentation can be found via projects for which the model has been used. To successfully implement the economic model, knowledge of constrained optimisation and mathematical programming is required; beyond this knowledge of economics and optimisation, experience with using the GAMS suite is recommended, along with a computer system able to run GAMS software.

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The economic model has been used within the MEDIATION project as a tool to assess the impacts of climate change (i.e. reduced water availability for irrigation, changes in crop yields, etc.) and to evaluate different policy options and their impacts on farm income, land use (cropping patterns) and water consumption in irrigation.


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## WEAP – The Water Evaluation and System Planning Model

**Description**

WEAP is a software tool for integrated water resource planning and policy analysis. WEAP operates on the basic principle of water balance and integrates natural processes (evapotransipiration, runoff, etc.) and engineering aspects (reservoirs, groundwater use, etc.) water systems. WEAP was created to be a decision support tool meant to assist skilled planners. The software is very user-friendly, with a GIS-based interface enabling easy visualization of system components and simulation results. (WEAP website, 2011). Specifically, we have used the MABIA method to simulate climate change scenarios. The MABIA Method is a daily simulation of transpiration, evaporation, irrigation requirements and scheduling, crop growth and yields, and includes modules for estimating reference evapotranspiration and soil water capacity.

WEAP has previously been used as a water balance database, used to record water demand and supply information; a scenario generation tool, simulating water supply and demand, runoff, storage, pollution generation, and more; and as a policy analysis tool, evaluating a range of water development and management options. For more details on previous research using the WEAP model, see: http://weap21.org/index.asp?action=205

**Strengths and Weaknesses**

| Key strengths | Potential weaknesses |
|---|---|
| flexibility in expanding level of detail<br>Very user-friendly<br>GIS-based interface enabling easy visualization of system components and simulation results<br>Integrated approach. Useful for developing integrated water resources planning assessments<br>Model integration. Dynamic links to other models and software, such as QUAL2K, MODFLOW, MODPATH, PEST, Excel and GAMS | Data demanding application. Availability of reliable data<br>Time scale. While natural processes occur on a daily basis, WEAP usually calculates water balance on a monthly time step<br>All crops share the same water priority, which means that shortages are equally share among crops. This is not very realistic in some Mediterranean areas, where in times of shortage perennial corps are satisfied before annual crops. |

**Applications**

The model can run daily, monthly or yearly time steps and provide results on supply requirements, unmet demands, ecological flows, reservoir operations, groundwater storage, hydropower generation, the evolution of soil moisture, evapotranspiration rates, etc. (Sieber and Purkey, 2007). In geographical terms, the model is applicable at sub-national scales.

Key inputs are data required to calibrate the model and accurately describe the water system under study, as well as data and trends to be used in scenario analysis (economic, demographic, hydrological, technological, etc.)

Key outputs of the model are scenario-based long-term effects of policy changes on a water system. The model is presented as assisting in providing answers to questions such as, What if population growth and economic development patterns change? What if reservoir operating rules are altered? What if groundwater is more fully exploited? What if water conservation is introduced?

**Accessibility**

An intuitive graphical interface provides a simple yet powerful means for constructing, viewing and modifying the system and its data. The main functions--loading data, calculating and reviewing results--are handled through an interactive screen structure that prompts the user, catches errors and provides on-screen guidance. The expandable and adaptable data structures of WEAP accommodate the evolving needs of water analysts as better information becomes available and planning issues change. In addition, WEAP allows users to develop their own set of variables and equations to further refine and/or adapt the analysis to local constraints and conditions. (WEAP website, 2011)

The tool is very user-friendly, and no technical knowledge of programming is required, however, a background in hydrology, water policy, or other related disciplines is desirable. The only technical requirement is a computer running Microsoft Windows. The tool is free to use with registration to the WEAP website.

The WEAP website <a href= “http://weap21.org/”> has published examples, tutorial videos, and a users guide on its website.

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## AquaCrop

### Description

AquaCrop is a crop water productivity simulation model developed by the Food and Agriculture Organization (FAO) of the United Nations; the model is the result and improvement of a key reference paper on agricultural yield responses to water (Doorenbos and Kassam, 1979). The model treats herbaceous crops and tree crops separately, and simulates growth of a crop species, striving to address conditions where water is a key limiting factor. AquaCrop is mainly intended for practitioners such as those working for extension services, governmental agencies, NGOs and various kinds of farmers associations, and is intended to be used in developing irrigation strategies when dealing with water deficit, determining a suitable crop calendar, and obtaining yield estimates for crops under a variety of environmental conditions (including climate change). Applications include: assessing water-limited, attainable crop yields at a given geographical location; as a benchmarking tool, comparing attainable yields against actual yields of a field, farm, or region; scheduling deficit and supplemental irrigation; supporting decisionmaking on water allocation; and many more uses, described in the AquaCrop website documentation. <a href= "http://www.fao.org/nr/water/infores_databases_aquacrop.html">

### Strengths and Weaknesses

| Key strengths | Potential weaknesses |
|---|---|
| Good balance between robustness and output accuracy<br>Developed and supported by FAO. Fast growing group of users world-wide<br>No specific training for use of the tool is required. It enables non-specialist to develop scenarios<br>Requires a relatively small number of explicit and mostly-intuitive parameters and input variables.<br>Ideally suited for the evaluation of climate impacts. Aquacrop simulates CO2 effects and permits to differentiate between crops with different sink capacities. | Not yet available for fruit trees<br>Not recommendable under saline conditions<br>Can overestimate the CO2 fertilization effect on crops<br>Further improvements of the model for soil nutrient depletion, pests, diseases, and frost are possible |

### Applications

The model estimates crop growth, given a set of climate and soil parameters, together with crop management. As the model was designed to assess crop response to water, it allows for the evaluation of climate variability and change impacts (changes in temperature, precipitation, and other climate variables, CO2 concentrations, reduced water availability) or environmental regulations (reduced water quotas) on crop yields. It is to be used for irrigation management, project planning, and scenario simulations at different scales. (AquaCrop website 2011, <a href= “http://www.fao.org/nr/water/aquacrop.html”>) The key output of the model is crop yield. A relatively small number of inputs are required, pertaining to soils, crop species being used, hydrology, and other environmental factors (ie climate change scenarios)

**Accessibility**

AquaCrop is designed to be relatively simple and intuitive, and to be used by practitioners, scientists, and educators as a training and education tool when dealing with the role of water in crop production. While there is no user interface, the process of running the application is relatively simple with the aid of a user's manual. No specific training for use of the tool is required, but knowledge of the concepts involved (agriculture, water use, etc.) is desirable, as well as a basic idea of how the software works, as there is no user interface. The only technical requirement is a computer system running Microsoft Windows, and the software is free to download after providing basic contact information. All required documentation, most notably the AquaCrop Reference Manual, can be found at: <a href= “http://www.fao.org/nr/water/aquacrop.html”>

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## Cost Effectiveness Analysis (CEA)

### Description

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 toproduce a cost-effectiveness ratio (CER): CER = E/C . If we suppose that there are i=1, 2,..., n potential policies, with corresponding costs Ci and effectiveness Ei then CEA requires that we rank the policies according to CERi = Ei / Ci.

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.

### Strengths and Weaknesses

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).

**Applications**

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.

**Accessibility**

CEA is not a proprietary tool or software package, and is discussed in the toolbox as the operationalization of the method. Thus, only limitation to access is the knowledge required to perform CEA.

Further information on CEA can be found via the in-depth Description in the Adaptation Task Navigator.

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## Cost Benefit Analysis (CBA)

### Description

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 Ct is the social costs and Bt 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 <= 0 or B/C <= 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.

### Strengths and Weaknesses

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).

**Applications**

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).

**Accessibility**

CBA is not a proprietary tool or software package, and is discussed in the toolbox as the operationalization of the method. Thus, only limitation to access is the knowledge required to perform CBA.

Further information on CBA can be found via the in-depth Description in the Adaptation Task Navigator.

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## Multi-criteria analysis (MCA)

### Description

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.

### Strengths and Weaknesses

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.

**Applications**

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).

**Accessibility**

MCA is not a proprietary tool or software package, and is discussed in the toolbox as the operationalization of the method. Thus, only limitation to access is the knowledge required to perform MCA.

Further information on MCA can be found via the in-depth Description in the Adaptation Task Navigator.

**References and Further Reading**


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## Bioclimatic Envelope Modeling

### Description

Bioclimatic envelope modeling is a process of spatially predicting species distributions, based on interpolations of data in space. Bioclimatic envelope models use associations between different aspects of climate and observed occurrences of species to define conditions under which species are most likely to maintain viable populations. These models, also known as species-climate envelope models, are correlated with ecological niche, habitat suitability, and species distribution models, but differ in certain ways, as only climate variables are taken into account, and not, for example, resources for species use.

Bioclimatic envelope modeling allows for the mapping of species distributions, which is assumed to be impractical to map directly. As species dsitribtuions can be predicted from environmental indicators, and more detailed projections of these environmental variables are available, one can predict the current or future distribution of a species much easier than by direct monitoring.

Spatial predictions such as envelope modeling can be used to better understand distributions of species, and predict the present or future occurrence of a species, to help conservation planning, assessing the status of a species or invasive species, projecting the effects of climate change, and more.

### Strengths and Weaknesses

### Applications

The model approach can be used to a number of novel questions, some of which are highlighted below:

- *the discovery of new populations and entirely new species:* Raxworthy et al (2003) discovered seven previously unknown species of Chameleon in Madagascar.
- *conservation planning*: Williams e al (2005) studied the possibility of the plant *Proteaceae* to shift its distribution in a region of South Africa.
- *Forecasting species distribution given the effects of climate change*: The MEDIATION Nordic case study deals specifically with this issue
- *Mapping the risk of disease transmission*: Peterson et al (2006) used modeling to predict the possible outbreak of hemorrhagic fever

### Accessibility

The modeling approach discussed here, while being seen as an easier method of predicting species habitats besides direct survey of their locations, is still demanding in terms of data and skills required to perform an accurate assessment. A range of environmental data is required; importantly, the links between climate and species distribution needs to be well understood by researchers, in order to accurately model projected distribution. Input data, such as future climate estimates, must be spatially organized. Further, use of this method requires knowledge of GIS software, and knowledge of the modeling methods involved (e.g. generalized linear models, generalized additive models, classification trees, random forests).

GIS software, such as ESRI's suite of tools, requires a significant purchase and/or use of a license. Open-source GIS tools exist, but without the support and usability of more mainstream programs.

### References and Further Reading


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## Grapevine Growth Model

### Description

The grapevine model (Bindi et al., 1996) uses a semi-empirical approach to simulate the main processes regulating development and growth of grapevine and has been already validated for Sangiovese variety. Crop development is divided in 2 periods: vegetative and fruit growth. The vegetative period, included between bud-break and bloom, is calculated on the assumption that bloom occurs when 17 leaves have appeared on the main shoot. The duration of fruit growth, between bloom and maturation, is assumed to be temperature-dependent and it is calculated using cumulative degree-days (1440) with a base temperature of 10°C.

Leaf area index (LAI) is calculated from the total number of shoots per unit area, the rate of leaf appearance and leaf expansion. LAI is, in turn, used to calculate the total amount of solar radiation intercepted by the canopy so that the crop biomass can be calculated as the product of this parameter and radiation use efficiency (RUE, g $MJ^{-1}$).

Daily fruit growth rate is calculated assuming that the harvest index HI (the ratio of fruit to current year's total biomass) increases linearly during fruit growth. Water stress is included in the model as reducing both LAI growth and RUE.

Additionally, the model takes into account of the effect of increased CO2 concentration ([CO2]) on physiological parameters: RUE was set to increase linearly by 30% for a doubling [CO2] (i.e. 700 ppm). According to the storyline of A2 and B2 scenarios [CO2] was set to increase proportionally from the present period (1990-2005, 350 ppm) to 2100 (700 and 550 ppm for A2 and B2 scenarios respectively).

### Applications

Grapevine phenology was used as indicator to assess the potential land suitability for grapevine cultivation. For each time-slice, the potential suitability of a site for grapevine cultivation was calculated as the ratio between the number of failed growing seasons (when maturation stage was not reached before the end of November) and total number of possible growing seasons (29). Accordingly, the degree of suitability ranged from 0% (no growing seasons completed) to 100% (all possible growing seasons completed). After interpolation (see after), a binary map was derived where 95% was considered the threshold of land suitability (>95%) or not suitability (<95%) for grapevine cultivation. The accuracy of this approach was tested for the present period PP, over the actual grapevine land cover, as derived by CORINE (CLC 2000). The results, visually evaluated, indicated the effectiveness of this methodology, to the extent that actual cultivated areas are completely included in grapevine potential distribution across the region.

**Accessibility**

The grapevine growth model is a tool developed by researchers at the University of Florence and described in Bindi et al (1996). It is recommended to contact researchers for more details about model access.

**References and Further Reading**

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## CATSIM – The Catastrophe Simulation Model

**Description**

Historically, a substantial part of the losses due to disasters in developing countries has been financed by relying on diversions from the budget, as well as loans and donations from the international community. This strategy involves considerable uncertainty with regard to the availability and timeliness of necessary funds, and for this reason emphasis is being put on financial planning.

This led to the development of the CATastrophe SIMulation model (CATSIM) to assess the financial vulnerability of the public sector to extreme events in hazard-prone developing countries and to illustrate the tradeoffs and choices a country government must make in managing the economic risks due to natural disasters.

The model can assist policy makers in developing public financing strategies for disaster risk, by showing the respective costs and consequences of financing alternatives on important indicators, for example, economic growth or debt. The model is equipped with a graphical interface that allows the user to change default parameters defining hazards, vulnerability and the elements exposed. There are two modules: the first assesses risk and the second shows the costs and benefits of different strategies to manage risk. Since the user can interactively change parameters and assumptions, financial strategies are shown in a transparent fashion. Furthermore, in another mode an optimal mix of ex-ante and ex-post measures can be calculated by solving a multistage stochastic optimization problem.

**Strengths and Weaknesses**

**Applications**

CATSIM has been used in a number of policy workshops in Honduras (2004), at IIASA (2004), in the Philippines (2006) and in the Caribbean (2006).

The IIASA workshop was the first to involve multiple countries. It was sponsored by the World Bank's Hazard Management (HMU) and the ProVention Consortium. Policy makers and practitioners from Colombia, Mexico, India, the Philippines, and Turkey interacted with IIASA and World Bank staff and consultants. The purpose of the workshop was to exchange insights and practice on loss-mitigation and pre-disaster financial strategies for reducing the vulnerability of the public and private sectors to the economic losses of disasters. Each of the participating countries is advanced in pre-disaster financial planning, or is considering developing advanced schemes.

The workshop demonstrated the potential of CATSIM for building the capacity of policy makers to evaluate ex-ante financial instruments, including insurance, catastrophe bonds, contingent credit arrangements and other disaster hedges, and compare their benefits with investments in loss reduction.

In a one day hands-on exercise as part of a recent two-day workshop on budgetary and financial approaches to disaster risk management in Barbados, senior representatives of Ministries of Finance and Planning, and National Disaster Coordinators from 18 Caribbean countries used CATSIM to develop strategies for financially coping with disaster risk. At this workshop, which was organized by the IDB and the Caribbean Development Bank (CDB), CATSIM was useful for putting into practice the workshop concepts and approaches for incorporating disaster risk management into fiscal and development planning, as well as exploring the feasibility of physical and financial disaster risk management options. At the request of participants, CATSIM was distributed to 10 Caribbean countries as well as CDB and IDB staff.

**Accessibility**

A version of the CATSIM model is made publicly available via the International Institute For Applied Systems Analysis' website. This version of the tool allows for an initial investigation of a country's financial risk and resilience, given a limited number of input parameters.

CATSIM utilizes risk curves depicting the probability of losing a percentage of capital stock in a disaster, as well as necessary economic input data such as national capital stock, budget, current debt estimates, and other factors that contribute to estimates of national exposure and financial resilience. Outputs of the model include an estimate of damages from return-period level events, a "resource gap" where a country can no longer finance the damages from a disaster, as well as estimates of the long term, indirect effects of a disaster on national development. Adaptation strategies can be pursued on an aggregate level, estimating the possibility and costs / benefits of balancing investments between growth and stability / resilience to events.

While limited data is needed as input, an understanding of extreme events, probability and extreme value theory is recommended when using the tool, and without proper training, results from the model should be taken as uncertain.

More in-depth analysis using the CATSIM methodology may be possible on a case-by-case basis; it is recommended to contact the researchers involved with any requests.

### References and Further Reading


Hochrainer-Stigler, S. and Mechler, R. (2013). Assessing Financial Adaptation Strategies to Extreme Events in Europe. Routledge (Forthcoming).

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Hochrainer, S. (2006). Macroeconomic Risk Management against Natural Disasters. German University Press (DUV), Wiesbaden, Germany.

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## Economic Impact Analysis

### Description

In the specific case of wine areas, the evidences used for the definition of the resilience degree of the wine cultivation have been brought back, on the one hand, to the entrepreneurial vitality and, on the other, to the specialization at municipal level in the cultivation of the examined species, considering also at the same time the relevance taken by the areas subject to quality production regulations DOC, DOCG, etc.. In fact, a high level of production specialization and quality is to be intended, in this case, as a synonymous of farm flexibility and reaction capability due to environmental and climatic alterations.

In this case, the economic loss linked with the wine regional component is to be intended as the missed incomes resulting from the damages undergone by the vineyards. Therefore, the starting datum needed for this typology of evaluation is the Gross Income of the Farm Production Process, which has been then calculated as the difference between the monetary value of the gross production of the activity itself and some specific costs (variable costs) (eq. 1).

$$GI = GP - VC \qquad (1)$$

where: GI = gross income; GP = gross production; VC = variable costs

Gross production, in turn, has been calculated as the product between the yield (q ha-1) and the value per unit of the total gross production (€ q-1), which means the value of the main product and/or of the processed product, the by-products and the Communitarian integrations. The variable costs are the costs linked with the interests on the capital assets, the remunerations for the seasonal workers and the costs for the acquisition of the inputs characterized by a total wearing out (which end their effect within the farm year).

In this way it has been possible to differentiate the costs and the incomes of the Tuscan wine cultivations both in relation to the plain, the hill and the mountain areas of the Tuscan Provinces, and in relation to exchange areas of the different designation of origin (Chianti Classico, Brunello, ecc.).

The appraisal process for the Gross Income of the Farm Productive Process for the future scenarios was based, instead, on the estimation of the existing correlation between the present Gross Income (2007) and the vine cultivation vulnerability levels for the years 2036, 2067 and 2099. In particular, the Gross Income of the Farm Productive Process, considered as the yearly profit (u), has been defined as it is shown in equation 2.

$$u_{2007} = a^{*}_{2007}$$
$$u_{FP} = u_{2007} \cdot (1 - vu\ln erability_{FP}) = a_{FP} \qquad (2)$$

Where: u2007 = Farm gross income year 2007 without production alterations ≡ a*2007 = annuity 2007

Thus, the Present Value has been estimated as an initial accumulation of “average” annuity for each referring period (2007-2036, 2036-2067, 2067-2099). The summation of the Present Values for the three referring periods (PA2007-2099), represents the revenue of the wine sector (at the present time – year 2007) net of the income reductions due to climatic changes.

The last phase regarded the definition of the total economic loss for the wine sector, aggregated at regional scale. The total economic loss (or financial loss – FL) will be given by the difference between the Present Value (PA*2007-2099) of the series of annuities that are likely to happen in the period 2007-2009 without an alteration of the production ( a* 2007), and the Present Value of the annuities that are likely to happen in the period 2007-2099, with alterations in the production (PA2007-2099).

$$FL = PA^*_{2007-2099} - PA_{2007-2099} = a^*_{2007} \cdot \frac{q^{2099-2007} - 1}{r\, q^{2099-2007}} - PA_{2007-2099} \qquad (5)$$

where:

PA*2007-2099 = present value of the annuities for the period 2007-2099 without productive alterations

r = rate of interest (3,5%)

**Applications**

This method is used in the Southern Europe case study pertaining to a changing climate's effects on wine producing regions in Italy. More details on the case study can be seen via the case study navigator.

**Accessibility**

The conceptual method presented above can be applied to various cases, but significant research and inputs in terms of impacts, vulnerability, and resilience is required. This method should not be seen as a standalone tool or "plug and play" method whereby a simple scenario can be run, but rather a detailed part of a larger study.

**References and Further Reading**

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## Zonation (Spatial Conservation Planning)

### Description

Zonation is described as "a framework and software for spatial conservation prioritization," essentially, a conservation planning decision support tool (SOURCE). The tool can assist decision-makers or advisers regarding conservation by identifying areas that are vital to preserve and maintain habitat quality and connectivity for [if necessary, multiple] species, with a goal of long-term species persistence. The tool allows for identifying both high and low priority areas for conservation, a balancing of alternative land uses, prioritizing of certain species or communities, as well as allowing for different approaches to conservation and perceptions of values.

Zonation can create scenarios analyzing the optimal spaces to be set aside as reserves, based on the various preferences indicated above, and iteratively chooses the optimal location for a reserve, simultaneously discarding least optimal regions, in order to produce a proposed geographic area which is both high in quality as well as contiguous, with the aim of species survival.

### Applications

Zonation software was applied by New Zealand's National Institute of Water and Atmospheric Research to evaluate potential areas to be designated as Marine Protected Areas, and documentation can be viewed at the zonation website (link can be found in the References section below).

The software has also been utilized in habitat restoration planning, planned expansion of conservation areas, and urban enviornments; details can be found on the Zonation website.

Typically, Zonation is used for large-scale and high resolution studies, current examples of research have typically been high-resolution national and sub-national scale assessments.

### Accessibility

As mentioned in the Applications section, Zonation software typically uses high resolution input data. Data needs change depending on analysis being performed, but typically, data on species being studied, their current presence or absence, probability of suitability of an area for a species, and ecological and climate qualities of the region, all spatially explicit, are required.

Zonation software is free to use and available via its creators. The researchers have also created a 300-page user's manual describing all steps needed to use the software, linked below. The user's guide describes, in great detail, the methodological steps of the tool, and explicitly describes its usage and limitations.

Both the software and user's manual can be found at:

<a href= "http://www.helsinki.fi/bioscience/consplan/software/Zonation/downloads.html">

### References and Further Reading


<a href= "http://www.helsinki.fi/bioscience/consplan/software/Zonation/index.html">

<a href="http://www.helsinki.fi/bioscience/consplan/software/Zonation/DOC06213_mpa%20report.pdf">

## LISFLOOD

### Description

The LISFLOOD model is a spatially explicit hydrological model created and used by the EC's Joint Research Centre. The model is capable of basin level simulation of hydrological processes such as evaporation, snow accumulation and melt, water uptake by vegetation, surface runoff, and ground water runoff, among other outputs. The simulation of these processes allows for the study of climate change and land use-change effects to a catchment, as well as the forecasting of floods and assessment of river regulation policies.

### Applications

LISFLOOD is able to output estimated heights of waterways during floods of a given probability at a very fine scale, allowing for projections of changing flood risk via the effects of climate change. This output is being utilized by the EU case study on flooding to assess the changing European flood risk and possible adaptation measures.

### Accessibility

LISFLOOD is a closed model developed by JRC, and access to the model is not given for outside use. Model results may be utilized for future research after their publication, but use of the model by outside researchers for work independent of the JRC is highly unlikely. However, a highly detailed user's manual and documentation of the methods used by the model is available via JRC; the link can be found below.

<a href= "http://floods.jrc.ec.europa.eu/files/lisflood/ec_jrc_lisfloodUserManual_JvdK-AdR.pdf?ml=5&mlt=system&tmpl=component">

LISFLOOD is spatially explicit and relies on a number of input data sources, ranging from land cover, soil characteristics, topography, and hydrological traits of the catchment. Additionally, climate and weather data are required: rainfall, evaporation, and daily temperature estimates. As a result, LISFLOOD is seen as having very high data requirements, and requires substantial computer processing power to utilize both the model and output data. High resolution data can be in the scale of 10 x 10 meter grids; for the EU flooding case study, a Europe-wide grid at this scale for different events (e.g. 50, 100, 250 year flood events) results in huge output datasets, making further use of the data problematic in the absence of enough computing resources.

### References and Further Reading

<a href= "http://floods.jrc.ec.europa.eu/lisflood-model">

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## Robust decision making

### Description

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 characterize 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 decision makers 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 characterize 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 decision-making becomes an exercise in juggling difficult trade-offs and judging which values and scenarios should weigh more heavily, and which should downplayed. The choice rests 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 decision makers 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).

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## Real Options Analysis

### Description

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.

ROA can be carried out in a variety of ways. The most relevant (to adaptation) is dynamic programming, which is an extension of decision-tree analysis. This defines possible outcomes, and assigns probabilities to these. The decision-tree defines how a decision-maker responds to resolution of uncertainty at each branching point. Quantifying the value of these decision options then proceeds by assessing all the branches. ROA calculates option values based on the expected value over all branches contingent on making the optimal choice at each decision-point. The optimal decision in turn is evaluated based on all the possible outcomes downstream of that decision in the tree. This ROA value can be compared to a normal appraisal calculation (a probability-weighted average) of the outcomes along each possible branch.

### Strengths and Weaknesses

A key strength is the economic comparison of investing now versus waiting, and the value of flexibility, i.e. comparing if the additional marginal cost (or lower initial benefits) of added flexibility is offset by the option value for future learning. ROA can also be used to support initial enabling steps to help secure projects for future development (should they subsequently prove to be appropriate) even if they are not expected to be cost-efficient on the basis of traditional, static Cost-Benefit or Cost-Effectiveness appraisal.

However, data constraints are a potential barrier, since a key input to ROA is probabilistic climate information that is combined with quantitative impact data. Since such probabilistic data is not yet available, and quantitative impact data is limited in many sectors, the scope for the practical application of ROA remains restricted. Further, for adaptation ROA needs to identify decision points in complex dynamic climate pathways and align with climate data (noting that time periods may not align); such identification may prove to be difficult in practice. Finally, the complexity of the analysis is likely to require expert application that constrains its up-take.

**Applications**

ROA has been widely cited as a decision support tool for adaptation and aligns closely with the concept of iterative decision making. A key strength is the economic analysis of investing now versus waiting, and the value of flexibility, i.e. comparing if the additional marginal cost (or lower initial benefits) of added flexibility is offset by the option value for future learning.

To date, the practical application of ROA to adaptation has been very limited. The UK Treasury (HMT 2009) provides a hypothetical example, incorporated into supplementary Government economic adaptation appraisal guidance. This uses decision trees and compares two alternative options: investing now in a single fixed-height sea wall defence, versus investing in a wall which has the potential to be upgraded in the future. The expected Net Present Value (NPV) is assessed under future low and high Sea Level Rise (SLR) scenarios, assuming these are equally likely. The results show the upgradeable wall, able to cope with high-end SLR scenarios, has a higher overall NPV. However, the application of ROA to the real world involves a further step change in complexity.

Jeuland and Whittington (2013) applies ROA to water resource investment planning on the Blue Nile (Ethiopia) - coupling hydrological models to Monte Carlo analysis - to identify flexibility in design and operating decisions for a series of large dams. Their results do not identify a single investment plan that performs best across future climate conditions, but highlights configurations robust to poor outcomes and flexible enough to capture upside benefits of favourable future climates.

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## Community Land Model (CLM)

### Description

The Community Land Model is part of a larger model suite called the Community Earth System Model (CESM). The model represents the land model for the modeling system, which aims to model changes in climate based on interaction of physical, chemical and biological processes in the atmosphere, oceans, and land surface. As described by UCAR (2012), the model "formalizes and quantifies concepts of ecological climatology… an interdisciplinary framework to understand how natural and human changes in vegetation affect climate". The model consists of component models relating to biogeophysics (the exchange of water, energy, and momentum with the atmosphere), hydrologic cycle (precipitation, evaporation, snow cover, plant interception of water, etc.), biogeochemistry (exchanges of chemicals with the atmosphere), and dynamic vegetation (how plants interact with the atmosphere, also succession and changing ecosystems).

The model emphasizes that terrestrial ecosystems have an important determinant effect on global climate. The model is quite robust, and can be used to describe numerous traits and cycles of an ecosystem, including:

- Vegetation composition
- Absorption, reflection, and transmittance of sunlight
- Heat transfer in soil and snow
- Soil hydrology (runoff, redistribution of water, drainage, groundwater, etc.)
- Urban energy balance and climate
- Carbon-nitrogen cycling
- Dynamic landcover change
- Dynamic global vegetation (UCAR 2012)

### Strengths and Weaknesses

| Strengths | Weaknesses |
|---|---|
| • **Mechanistic description of the fire process**<br>• **Ability to catch complex interactions between biophysical processes and fires**<br>• **Description of the anthropogenic impacts on spatio-temporal fire patterns** | • High computational complexity<br>• Long computational time |

### Applications

The Community Land Model is predominately used as a component of the Community Climate System Model, and inputs into the CCSM are utilized to model global climate change. The CLM itself allows for numerous modeling possibilities; it is used by the EU Forest Fire case study to model future areas at risk of fires, and possible adaptation measures to reduce risk (Kloster et al 2010). Other modeling uses are described in the description above.

### Accessibility

The CESM model suite is offered for download by the National Center for Atmospheric Research, and extensive user's guides are provided for both the main model and sub-components such as the CLM, but users should note that this is not a model which may easily be implemented on a personal computer, as it requires a relatively large amount of computing power. Extensive knowledge of the models, and an understanding of programming in different languages is also required, and while the user's guide is extensive, use of CLM is not to be seen as something which can be done easily.

To obtain the CESM source code, free registration is required, as well as a valid email address.

Link to user's guide of CLM:

<a href= “http://www.cesm.ucar.edu/models/clm/”>

Link to CESM download:

<a href= “http://www.cesm.ucar.edu/models/”>

**References and Further Reading**


<a href= “http://www.cesm.ucar.edu/models/”>

<a href= “http://www.cesm.ucar.edu/models/clm/”>

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<a href= “http://journals.ametsoc.org/doi/pdf/10.1175/JCLI3742.1”>

<a href= “http://www.biogeosciences.net/7/1877/2010/bg-7-1877-2010.pdf”>

## The Climate Impacts LINK Project

### Description

The Climate Impacts LINK Project is a dataset managed by the British Atmospheric Data Centre (BADC), containing output results from a number of climate models and experiments conducted by the Hadley Centre. Most of the datasets are from global HadCM3 and regional HadRM3 model runs.

### Applications

The BADC provides access to a number of model runs, and provides documentation as to the format, structure, and outputs of the datasets, but does not provide insight as to choosing one dataset over another, and recommends consulting expert advice for such decisions. They suggest that the UK Met Office scientists involved in the modeling can be helpful in this regard.

As to output results, they range in scope from global to regional coverage, and are provided in daily and monthly average values. Most outputs relate to atmospheric qualities, although ocean traits are supplied by some models as well. Once chosen, selected outputs can be used as inputs into various assessments of climate change impacts and adaptation. Downscaling (described in the MEDIATION toolbox) can be used to facilitate analysis at a more precise spatial resolution.

### Accessibility

Datasets are provided by the BADC free of charge for research use, for other uses (e.g. commercial) users should contact the curators; there are no specific computer or training requirements, although it is necessary to have an understanding of model assumptions and processes; expert guidance is recommended.

### References and Further Reading

Access to the data archives can be found at:

<a href= “http://badc.nerc.ac.uk/data/link/”>

The BADC can be contacted at:

The British Atmospheric Data Centre, Space Science and Technology Department
badc@rl.ac.uk
R25- Room 2.122,
CCLRC Rutherford Appleton Laboratory, Chilton, nr Didcot,
Oxfordshire, OX11 0QX, England, UK;
Tel: +44.1235.44. 64.32;
Fax: +44.1235.44.63.14.
UK Met Office: <a href= “http://www.metoffice.gov.uk/”>

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## NCEP Global Ocean Data Assimilation System (GODAS)

### Description

GODAS consists of a dataset of ocean properties, maintained by the National Centers for Environmental Prediction (NCEP). The dataset consists of real time analysis of ocean temperatures and salinity, as well as historical estimates from the years 1979 – 2004. The goal of GODAS is to enable study of global climate, as well as analysis of sub-seasonal, seasonal, and interannual variability of the ocean.

### Applications

As mentioned in the Description, GODAS can provide inputs into studies of climate change impacts, as well as studies of ocean variability, as the dataset provides estimates of ocean temperature, salinity, and movement at a global scale.

### Accessibility

There is no charge for use of the data, and users can download datasets via web browser. Knowledge of FORTRAN may be helpful to extract data, but specific plots can also be downloaded via the GODAS website. All relevant documentation is provided on the website.

### References and Further Reading

Further documentation on the GODAS data can be found at:

<a href= “http://www.cpc.ncep.noaa.gov/products/GODAS/pl/introduction_godas_web.pdf”>

and the GODAS website.

Access to the data is provided at:

<a href= “http://www.esrl.noaa.gov/psd/data/gridded/data.godas.html”>

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## RClimDex

### Description

RClimDex is a graphical user interface which allows for easy calculation of 27 climate extreme indices, such as the number of frost days, number of summer days, growing season length, daily temperature extremes, and more. Constructing these indices is useful in climate change monitoring and trend detection. RClimDex was designed to assist in analyzing climate data from weather stations from any pat of the world, allowing for combining and homogenizing of disparate data points to create a single map of data.

### Applications

RClimDex can be used to combine disparate data points, such as a range of data points from weather stations, into one set which can be used in analysis of current climate, in monitoring and evaluation, as well as trend detection, decision-making steps of larger climate change analyses.

### Accessibility

The tool is provided with a graphical interface, allowing for users not proficient with statistical software to still combine data points and calculate indices. The software utilizes the R statistics program, and needs to be installed. All instructions as to installation of required packages, as well as use of the tool, is documented in a user's guide, made available on the tool website. No other special requirements exist besides a computer.

### References and Further Reading

For further information, see:

<a href= "http://cccma.seos.uvic.ca/ETCCDMI/software.shtml">

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## SimCLIM

### Description

SimCLIM is a tool designed to support climate change decision making in a number of situations and sectors. The model allows for linking of user input data and models with global climate scenarios, and assessing various projected global changes and extreme event probabilities in the future, as well as current variability and extremes. The program allows for importing spatial and time-series data into a GIS viewer, and contains data from many different GCM runs and scenarios, such as SRES emissions scenarios.

### Applications

As mentioned above, SimCLIM is able to be used to describe current climate baselines, variability, and extremes, as well as to generate and analyze future climate scenarios, assessing climate risks and adaptation options, and examining uncertainties. The GIS viewer allows for analysis at different spatial scales, from global to local, but uncertainties depend on both scenarios involved as well as the resolution of input data. There is also an ability to use location-specific tools to analyze time series point data and impact models. The key output of SimCLIM is the ability to analyze scenarios of climate and sea-level changes, as well as sectoral impacts, mainly for water, ecosystems, agriculture, health, and coastal zone issues.

### Accessibility

While SimCLIM provides both observed climate data as well as GCM runs and scenario inputs, the model requires various inputs at either national or local scales, depending on the user's application goals. The program allows for importing of spatial and time-series data. The software itself is very accessible to use, and training sessions can be attended. There are no specific requirements for using the tool, however the program requires a license, which may be purchased on an individual basis.

### References and Further Reading


A user's guide for SimCLIM, plus access to the tool, can be found at:

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## Statistical DownScaling Model (SDSM)

### Description

SDSM is a software tool allowing for the creation of high-resolution climate information based on coarser, large scale GCM estimates. The model operates via statistical downscaling methods, and can create ensembles of daily weather scenarios. SDSM also functions as a weather generator; using statistical techniques to generate realistic daily sequences of weather, i.e. precipitation, temperature, etc.

### Applications

SDSM may be used for impact and adaptation assessments requiring local or small-scale climate data with finer resolutions than GCMs.

### Accessibility

SDSM requires GCM outputs to downscale, as well as observed climate data used to calibrate and validate the tool. It runs on Windows PCs, and is freely available at:

<a href= “https://copublic.lboro.ac.uk/cocwd/SDSM/”>

### References and Further Reading

Please see <a href= “https://co-public.lboro.ac.uk/cocwd/SDSM/refs.html”> for a full list of SDSM references.

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## MAGICC/SCENGEN

### Description

MAGICC and SCENGEN is a package of two tools distributed by a researcher at UCAR; MAGICC is a gas cycle and climate model which has been used to make projections of future global temperatures and sea level change, based on chosen emission scenarios. SCENGEN allows for downscaling of the MAGICC outputs to a regional level.

### Applications

The set of models are applicable in any analysis of future composition of the atmosphere, climate, or sea level. SCENGEN allows for the results to be output at a 5 degree square grid, allowing for global and more regional, but still large scale, analysis.

### Accessibility

The tools are provided free to use by the developer; the only requirements are a computer, and a user's manual is provided to explain use of the tools. SRES scenario inputs are required to drive MAGICC.

The primary developer, Tom Wigley, can be contacted at wigley@ucar.edu.

See also: <a href= "http://www.cgd.ucar.edu/cas/wigley/magicc/">

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## COSMIC2

### Description

COSMIC2 is a tool which provides researchers and policy analysts a way to generate country-specific climate change scenarios. As most researchers do not have access to the computing power required to run GCM models, COSMIC2 provides access to national-level climate and sea level estimates for a range of emissions scenarios, allowing for use of consistent and proven GCM runs.

### Applications

COSMIC2 provides national-level climate change projections for 158 countries; this data can be used as inputs to any further impact or adaptation analysis.

### Accessibility

As stated above, COSMI2 outputs national level estimates for 158 countries; outputs include monthly estimates of average temperature and precipitation, as well as annual mean temperature, sea levels, and CO2 concentration. The tool only requires user inputs in terms of selecting a GCM and emissions scenario. COSMIC2 is free to use, and is provided on request by EPRI.

Send request to Larry J. Williams (ljwillia@epri.com)

### References and Further Reading

Schlesinger, M.E. and S. Malyshev, 'Changes in near-surface temperatures and sea level for the Post-SRES CO2-stabiliztion scenarios', Integrated assessment, 2: 95-110.

Schlesinger, M.E., S. Malyshev, E.V. Rozanov, F. Yang, N.G. Andronova, B. de Vries, A.Grübler, K. Jiang, T. Masui, T. Morita, J. Penner, W. Pepper, A. Sankovski and Y. Zhang, '2000: Geographical distributions of temperature change for scenarios of greenhouse gas and sulfur dioxide emissions.', Tech. Forecast. Soc. Change, 65, 167-193.

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Yohe, Gary and Schlesinger, Michael E.: 1998,'Sea-Level Change: The Expected Economic Cost of Protection or Abandonment in the United States', Climatic Change, 38: 337-472.

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## Providing Regional Climates for Impact Studies (PRECIS)

### Description

PRECIS, developed by the UK Met Office, is similar to the COSMIC2 tool in providing access to downscaled climate data based on the Hadley Centre's regional climate modeling. It was developed in order to assist developing countries by giving them free to use access to the tool and providing high-resolution regional climate projections.

### Applications

PRECIS provides regional climate data for use in regional or national impact and adaptation analysis. It has previously been used for studies in regions of Asia, Central America, Africa, and China.

### Accessibility

The PRECIS model, while supplied free of charge, requires a deep background in climate modeling in order to generate robust results; required inputs to the tool are GCM output estimates and details about the area to be modeled, and other parameters necessary for validation. The software requires a Linux PC to run; the faster the better, as runs could take as long as 2.5 months to complete running on a processer with limited computing power (a quad-core processor would take an estimated 8 weeks).

The Hadley Centre has run training seminars in the past, and staff are available to consult on use of the tool. The tool is supplied free of charge, along with accompanying documentation, to users from developing countries and those with economies in transition. Developed country institutions are charged 5,000 Euro.

### References and Further Reading

For more information, see: <a href= "http://www.metoffice.gov.uk/precis/intro">

UNFCCC, 2005. Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change. [online] Available at: <http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/2674.php> [Accessed August 2013].

## Policy Exercise

### Description

Policy exercises are described as "a flexible structured method designed to synthesize and assess knowledge from several relevant fields of science for policy purposes directed towards complex, practical management problems." Policy exercises allow for interaction between scientists, academics, and policy makers via scenario generation and scenario analyses via interactive policy creation and testing.

### Applications

Policy exercises can be used to identify possible adaptation options, or evaluate various options. This process is highlighted as being beneficial in phases of regional adaptation studies, either in helping to structure the problem or determine if policy responses are complementary or not.

### Accessibility

There are a number of documents written about policy exercises, which can be found in the References section. These should guide the user toward a greater understanding of the process involved in carrying out a policy exercise.

### References and Further Reading


Brewer, G.D. and M. Shubik. 1979. The War of Game: A Critique of Military Problem Solving. Harvard University Press, Cambridge, MA.

Toth, F.L. and E. Hizsnyik. 2005. Managing the inconceivable: participatory assessments of impacts and responses to extreme climate change. International Institute for Applied Systems Analysis. Working Paper FNU74.

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UNFCCC, 2005. Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change. [online] Available at: <http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/2674.php> [Accessed August 2013].

## Tool for Environmental Assessment and Management (TEAM)

### Description

The TEAM program allows for the graphical comparisons of relative strengths and weaknesses of adaptation strategies given user evaluation of issues such as equity, flexibility, and policy coordination. While not a tool to identify an optimal strategy, TEAM allows a user to clarify strengths and weaknesses of varying options.

### Applications

TEAM allows for consideration of a wide range of criteria for analysis, and should be utilized with other decision-making tools (CEA, CBA, MCA, etc.) to assess adaptation options.

### Accessibility

TEAM is designed to be run on a Windows computer, and requires little prior knowledge or training; the user should have an understanding of key policy objectives, but tool-specific knowledge required is minimal, and documentation / a user's guide is provided.

The tool is made available by the U.S. EPA, and documentation is offered for free, but no further details on access to the tool itself. For further information, contact:

Susan Herrod-Julius, 8601D, U.S. EPA Headquarters. Ariel Rios Building, 1200 Pennsylvania Avenue, N.W., Washington, DC 20460; Tel: 202.564.3394; e-mail: herrodjulius.susan@epa.gov.

### References and Further Reading

Smith, A., H. Chu, and C. Helman. 1996. Tool for Environmental Assessment and Management: Quick Reference Pamphlet. Decision Focus Incorporated, Washington, DC.

Smith, A., H. Chu, and C. Helman. 1996. Applications of Tool for Environmental Assessment and Management. Decision Focus Incorporated, Washington, DC.

Burton, I., J. Smith, and S. Lenhart. 1998. Adaptation to climate change: Theory and assessment. In Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies, J. Feenstra, I. Burton, J. Smith, and R. Tol (eds.). UNEP and Vrije Universiteit Amsterdam, Amsterdam, The Netherlands.

Herrod Julius, S. and Scheraga, J.D. The TEAM Model for Evaluating Alternative Adaptation Strategies.

UNFCCC, 2005. Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change. [online] Available at: <http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/2674.php> [Accessed August 2013].

## Adaptation Decision Matrix (ADM)

### Description

The ADM tool uses multi-criteria assessment methods to evaluate relative effectiveness and costs of various adaptation options, based on user's input evaluation criteria. Users rate adaptation options based on a scoring system of multiple criteria and input cost estimates, allowing for multicriteria analysis and cost-effectiveness analysis.

### Applications

ADM can be applied when multicritera analysis or cost-effectiveness analysis is necessary, useful when policy objectives cannot easily be monetized or expressed via a common metric. ADM can be applied for all sectors and spatial scales

### Accessibility

The tool itself is easy to apply and requires no special technical assets or skills, however users require proficiency in estimating costs of adaptation measures.

The tool is free to use, and a user's guide and the tool are made available by Stratus Consulting. For more information, contact:

Joel Smith, Stratus Consulting, P.O. Box 4059, Boulder, CO 80306 USA; Tel: +1.303.381.8000; Fax: +1.303.381.8200; e-mail: jsmith@stratusconsulting.com; website: <a href= “http://www.stratusconsulting.com/”>

### References and Further Reading


Mizina, S.V., J.B. Smith, E. Gossen, K.F. Spiecker, and S.L. Witkowski. 1999. An evaluation of adaptation options for climate change impacts on agriculture in Kazakhstan. Mitigation and Adaptation Strategies for Global Climate Change 4:25-41.

UNFCCC, 2005. Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change. [online] Available at: <http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/2674.php> [Accessed August 2013].

## Screening of Adaptation Options

### Description

Screening of adaptation options assists decision-makers in the beginning of a decision-making process, allowing users to create a broad list of options which can be analyzed in depth. The tool forces users to develop evaluation criteria, such as highlighting effectiveness, expenses, feasibility, costs/benefits, etc., which the user then evaluates a range of measures against.

### Applications

This tool can be used for any adaptation analysis, involving any spatial scale and sector. The only required inputs are some basic summary details about various adaptation options, and the tool results in a matrix outlining Strengths and Weaknesses of the listed options.

### Accessibility

The screening matrix is made available by Stratus Consulting; contact information is listed below:

Joel Smith, Stratus Consulting, P.O. Box 4059, Boulder, CO 80306; Tel: +1.303.381.8000; Fax: +1.303.381.8200; e-mail: jsmith@stratusconsulting.com; website: <a href= ”http://www.stratusconsulting.com/”>

There is no cost for use of the tool, and documentation and the matrix template are made freely available upon request.

### References and Further Reading

Mizina, S.V., J.B. Smith, E. Gossen, K.F. Spiecker, and S.L. Witkowski. 1999. An evaluation of adaptation options for climate change impacts on agriculture in Kazakhstan. Mitigation and Adaptation Strategies for Global Climate Change 4:25-41.

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## Business Area Climate Impacts Assessment Tool (BACLIAT)

**Description**

The UKCIP Business Areas Climate Impacts Assessment Tool (BACLIAT) allows for exploring the implications of climate change on a particular organization or sector. It comprises a simple checklist for assessing the potential impacts of climate change to different aspects of an organization: logistics, finance, markets, process, people, premises and management implications. Designed for use by the business sector, BACLIAT encourages considering threats and opportunities at a organizational or industrial-sector level.

**Applications**

BACLIAT can be used by an individual but is of most value when used as the basis of a brainstorming exercise with a group of relevant managers or representatives from the organization or sector in question. It can also be used in more general awareness-raising workshops to illustrate the breadth of impacts that climate change could have. The tool was designed to be used at a industrial sector or individual business scale, but could be applied to other sectors and scales. BACLIAT has been used by trade associations and companies in the UK.

**Accessibility**

The tool is free to use and access, and requires no special knowledge, outside knowledge of the organization or sector in question, as well as a background knowledge on climate change. BACLIAT is provided by the UKCIP, who may be available to facilitate workshops. Documentation is available from UKCIP, for further information, contact:

Kay Johnstone, Project Officer (Business), UK Climate Impacts Programme; e-mail: kay.johnstone@ukcip.org.uk.

**References and Further Reading**


Metcalf, G. and K. Jenkinson. 2005. A Changing Climate for Business, UKCIP.

UNFCCC, 2005. Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change. [online] Available at: <http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/2674.php> [Accessed August 2013].

## Community-based Risk Screening Tool – Adaptation & Livelihoods (CRiSTAL)

### Description

CRiSTAL was designed to help project planners and managers to integrate risk reduction and climate change adaptation into community-level projects. CRiSTAL was developed in response to the outcomes of a project, which examined how ecosystem management and restoration (EM&R) or sustainable livelihoods (SL) projects reduced community vulnerability to climate stress. CRiSTAL is intended to promote the integration of risk reduction and climate change adaptation into community-level projects. By focusing on community-level projects, CRiSTAL promotes the development of adaptation strategies based on local conditions, strengths and needs.

### Applications

CRiSTAL is designed for use at a local scale, by communities, project planners, and managers. The tool has been tested in case studies pertaining to natural resource management projects in such places as Mali, Bangladesh, Tanzania, Nicaragua, and Sri Lanka. The tool provided a link to discussing climate change and observed changes at a local level, and encouraged community-level adaptive capacity increases.

### Accessibility

Input requirements for using CRiSTAL is minimal; users should have information on climate change in the region of study and information on local vulnerabilities and resilience.

The tool is free to use, and is available on the web via IISD. There is no cost of access, and a user's guide is provided. The tool is provided as a self-extracting executable program; the only requirement is to download the files to a folder on the C: drive titled "CRISTAL". To run the tool, open the file "Session-Setup.xls" in the folder created. Further information can be found in the user's guide.

<link><a href=" http://www.seius.org/Cristal/Cristal_Setup.exe"> </link>

<linkdesc>Link to the CRiSTAL tool download,</linkdesc>

### References and Further Reading

For more information, contact:

Anne Hammill, Livelihoods and Climate Change Project Manager, International Institute for Sustainable Development (IISD); e-mail:ahammill@iisd.org.

UNFCCC, 2005. Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change. [online] Available at: <http://unfccc.int/adaptation/nairobi_work_programme/knowledge_resources_and_publications/items/2674.php> [Accessed August 2013].

## Variable Infiltration Capacity (VIC)

### Description

VIC is a macro-scale hydrological model, created by Xu Liang at the University of Washington, designed to process inputs from a global circulation model and simulate properties and effects on different modules: land cover and soil, snow, meteorology, frozen soil, lakes and wetlands, and flow simulations. VIC models the interactions and flow of water between the various modules, over a range of spatial scales, at daily or sub-daily timescales. The model notably excludes stream flow, requiring a separate model, and focuses on land surface simulation. The various modules allow VIC to consider different land cover types, regardless of geographic location, multiple soil layers, snow on the ground, surface of lakes, and in vegetation canopy, as well as frozen soil and permafrost. A dynamic lake and wetland model was added to the latest version of VIC, allowing for the modeling of permanent lakes and seasonal flooding (wetlands) inside of the model's grid squares, with river flow modeling being performed separately from the rest of the land surface model.

### Strengths and Weaknesses

| | Strengths | Weaknesses |
|---|---|---|
| **Coupled VIC-RBM model** | • Process-oriented approach<br>• possibility to produce transient data | • large spatial resolution and lack of spatial detail<br>• no projections of point source evolution<br>• models are developed to simulate high discharge events and are not well adapted to low flows |
| **VIC and HBV Rhine model** | • the combination of two different model suits(one process based, the other empirical) allows for analysis of model uncertainties in outcomes | • using chains of scenario, GCM/RCM, hydrological models introduces a cascade of uncertainties. The quality of uncertainties and variations in model outcomes are difficult to assess.<br>• models are developed to simulate high discharge events and are not well adapted to low flows |

### Applications

The model has been used in a number of watershed studies in the United States (Columbia, Ohio, and Upper Mississippi rivers), as well as a global analysis. VIC is part of an experimental surface water monitoring website run by the University of Washington, with the goal of presenting as close to real-time as possible monitoring of the continental U.S. for developing flood or drought conditions. VIC can be driven by observed or simulated data, and is thus suited for both present- and future- time slices.

### Accessibility

The VIC model source code is made freely available via the University of Washington, however, there is a significant amount of experience required to operate the model. VIC is written in C, and runs only on Linux-based computers. Depending on the scope of analysis, numerous input files need to be collected and properly formatted for use by the model. As VIC is very processing intensive, it requires a Linux cluster to run on, and a reagular desktop machine will probably not have the necessary computing power.

The VIC website provides a guide for user's wishing to install and run the tool, as well as frequently asked questions and periodic updates to the source code.

<link><a href="
http://www.hydro.washington.edu/Lettenmaier/Models/VIC/SourceCode/Download.shtml"> </link>

<linkdesc>Link to the VIC tool download</linkdesc>

### References and Further Reading

Liang, X., D. P. Lettenmaier, E. F. Wood, and S. J. Burges, 1994: A Simple hydrologically Based Model of Land Surface Water and Energy Fluxes for GSMs, *J. Geophys. Res.*,99(D7), 14,415-14,428.

Gao, H., Q. Tang, X. Shi, C. Zhu, T. J. Bohn, F. Su, J. Sheffield, M. Pan, D. P. Lettenmaier, and E. F. Wood, 2010: Water Budget Record from Variable Infiltration Capacity (VIC) Model. In Algorithm Theoretical Basis Document for Terrestrial Water Cycle Data Records (in review).

<a href= "http://www.hydro.washington.edu/forecast/monitor/research.shtml">

## Regional Atmospheric Modeling System (RAMS)

### Description

RAMS is a atmospheric circulation simulation model developed by Colorado State University in the 1980's; it was originally created out of a merging of three separate atmosphere models. RAMS predicts atmospheric circulation and phenomena at a number of scales, from entire hemispheres to horizontal scales of around 2 km, and is used for a variety of Applications such as weather forecasting and air quality regulatory Applications (Cotton, 2003). The model is based off of dynamical equations which accurately represent atmospheric motion, and incorporates factors such as radiation, formation and interaction of clouds, soil and vegetation, surface water, and topography.

### Applications

As the model is not limited in spatial scale, it can be used to model and study small scale phenomena such as tornadoes, as well as such low level occurances as turbulent flow over buildings and in wind tunnels. At the same time, it is possible to model on much larger scales, up to the level of hemispheres. It has been used for numerous studies, which can be found in the references below, and has been coupled to other models to study ocean-atmosphere interactions, and can provide input data to impact models dealing with extreme precipitation and climate change.

### Accessibility

The RAMS model is maintained by researchers at Colorado State, and does not appear to be available for outside use.  For more information and contact details, see the website for the research group responsible for the model.

<link> <a href= "http://rams.atmos.colostate.edu/"></link>

<linkdesc>Link to research group homepage</linkdesc>

### References and Further Reading

W. R. Cotton, R. A. Pielke Sr., R. L. Walko, G. E. Liston, C. J. Tremback, H. Jiang, R. L. McAnelly, J. Y. Harrington, M. E. Nicholls, G. G. Carrio, and J. P. McFadden. 2003. RAMS 2001: Current status and future directions. *Meteorol Atmos Phys* 82, 5–29.

<a href= "http://rams.atmos.colostate.edu/">

<a href= "http://rams.atmos.colostate.edu/rams-Description.html">

## COSMO-CLM

### Description

COSMO-CLM is actually titled the COSMO model in CLimate Mode. COSMO is a weather prediction model developed by a group titled the COnsortium for SMall Scale MOdeling. The Climate Limited Area Modelling Community consists of a number of universities and research institutes, spanning Europe and including partners in Africa, North and South America, and Asia. COSMO-CLM (or just CCLM) is a regional climate model based on a model from the German Weather Service. The model was developed for the purposes of weather forcasting, but can be used for studies of climate change and adaptation.

### Applications

CCLM is designed to be used at spatial resolutions between 1 and 50 km, and temporal scales up to centuries. The Applications of the modeling system are varied, recent work includes analysis of summer monsoons in East Asia, modeling precipitation patterns in Africa, and assessing patterns of European heatwaves, among many others. For a full list of research and publications, see the links in the references below.

### Accessibility

The CCLM model system is not available for use by anyone outside of the consortium research groups. There are however quite a large number of downloads and a large amount of documentation available explaining the processes and use of the tool, which can be found at the consortium website. The tool is quite complex and requires a great deal of expertise to use.

<link><a href=” http://www.clm-community.eu/index.php?menuid=1”></link>

<linkdesc>Link to the CCLM Consortium website</linkdesc>

### References and Further Reading

Kaspar, F., U. Cubasch: Simulation of East African precipitation patterns with the regional climate model CLM, Meteorol. Z., 17 (4), 511-518.

Dobler, A., B. Ahrens, 2011: Four climate change scenarios for the Indian summer monsoon by the regional climate model COSMO-CLM. JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, D24104, 13 PP., DOI:10.1029/2011JD016329.

Fischer, E.M. and Schär, C., 2010: Consistent geographical patterns of changes in high-impact European heatwaves. Nature Geoscience, 3, 398-403, doi:10.1038/ngeo866.