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ORIGINAL ARTICLE

Frontiers of solution-oriented adaptation research

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Abstract Adaptation is heterogeneous and relevant for a range of sectors and levels of decision-making. As adaptation moves up the policy agenda, solution-oriented adaptation research requires addressing questions that are salient to stakeholders and decision-makers at various scales and involves applying a wide range of different methods. Yet while solution-oriented adaptation research is being increasingly undertaken, there is to date a lack of synthesis of these experiences in the literature. In this paper, we aim to address this gap by synthesising findings in nine cases from the MEDIATION project (Methodology for Effective Decision-making on Impacts and AdaptaTION), an EC-funded solution-oriented adaptation research project. We do so by, first, describing methods applied for solution-oriented research in Europe and sequences of methods carried out in individual cases. Second, we assess strengths and weaknesses of individual methods in given empirical situations. Third, we analyse patterns observed in the sequences of methods and reflect on their implications for adaptation research. A strength of our approach is that detailed data on choices of research questions and methods were collected through in-depth and iterative interaction with the case study teams. We find that there is no standard recipe for adaptation; that even though social science methods are often indicated, they are often not applied; and that robust decision-making methods, while available, are often constrained because of their resource intensity. Reflecting on the implications of these findings, we argue that greater flexibility and transdisciplinarity are needed in adaptation research and that social science methods should be further supported. Finally, we find that stakeholder engagement is not a panacea and that engagement requires a more differentiated understanding of stakeholders and careful design in order to be effective.

Keywords Adaptation · Climate change · Robust decision-making · Institutions · Impact assessment · Social science · Europe

Introduction

More is being demanded of adaptation research as climate change impacts are occurring and future climate changes become increasingly unavoidable. The IPCC Fifth Assessment Report finds with *medium to high confidence* that in some regions, climate change is already impacting natural and human systems at a range of scales and in diverse sectors (IPCC 2014).

In Europe, climate change is leading to retreating glaciers (Huss 2011) potentially increasing risks of both riverine flooding (Rojas et al. 2013) and low-flow events in the long term (van Slobbe et al. 2014), while risks of coastal flooding have increased in many areas due to observed rise in mean sea level (EEA 2012). High-temperature extremes have become more frequent over the past several decades (Hartmann et al. 2013), leading to increasing wildfire risk in southern Europe (IPCC 2014), and increased health risks due to heat waves in Scandinavian

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countries (Carter et al. 2014). In central and southern Europe, increased climate variability has produced increasing variation in agricultural yields (Brisson et al. 2010), while changing temperature and precipitation patterns will decrease suitability of wine production in southern Europe for currently used varieties (Metzger and Rounsevell 2011).

New adaptation challenges are thus imminent and diverse arising from a range of different hazards, in different sectors and on different timescales. Adaptation research is not restricted to assessing risks on a century scale or to cost calculations to complement mitigation decision-making, rather adaptation research is becoming solution oriented. In opposition to basic research, solution-oriented adaptation research requires addressing questions that are salient to stakeholders and decision-makers at various scales (Cash et al. 2003).

Moreover, solution-oriented adaptation research now requires addressing a wider range of issues arising in supporting the identification, selection and implementation of adaptation options tailored to decision-makers' situations. This view is articulated most forcefully by the growing literature on barriers to adaptation, namely that in many cases improved information on climate risks may not be sufficient, or even most important, for advancing adaptation (Moser and Ekstrom 2010; Dilling and Lemos 2011; Lemos et al. 2012; Biesbroek et al. 2013). Instead social science methods, less prominent in adaptation research up to now, may be applied to understand and overcome barriers to adaptation in the implementation process (Agrawal et al. 2012).

An ever increasing amount of solution-oriented adaptation research is currently underway around the globe, representing a broad range of approaches from regional biophysical and economic impact assessment (Ahmed and Suphachalasai 2014) to community-based (ADB 2013) and business-oriented vulnerability assessment (UKCIP 2010) to institutional analysis (Graham et al. 2014) and monitoring and evaluation of adaptation (Bours et al. 2014).

Yet, while the volume of solution-oriented adaptation research is increasing, there is to date a lack of synthesis of these experiences in the literature. For instance, the IPCC Summary for Policy-makers notes that in Europe, most adaptation research has focussed on prioritisation of options, while relatively little is known about the implementation or effectiveness of different options (IPCC 2014). Moreover, knowledge emerging from these different activities remains largely unrelated to one and other (Hofmann et al. 2011). Little analysis exists of how effective given methods are with respect to particular empirical settings, e.g. little is known about the relationship between conducting climate impact assessments and adaptation on the ground. Relatedly, while several authors have argued that the choice of methods may influence what problem is addressed and what adaptation measure is chosen (O'Brien et al. 2007; Bisaro et al. 2010), there is little systematic analysis of the implications of applying a particular method or sequence of methods for subsequent research and practice.

This paper aims to address these gaps by synthesising findings in nine European cases from the MEDIATION project (Methodology for Effective Decision-making on Impacts and AdaptaTION), an EC-funded solution-oriented research project. We do so by, first, describing methods applied for solution-oriented research in Europe and sequences of methods carried out in individual cases. This provides a descriptive analysis of state-of-the-art solution-oriented adaptation research in Europe, illustrating the wide range of methods now being applied. Second, we assess the strengths and weaknesses of individual methods in given empirical situations. Third, we analyse patterns observed in the sequences of methods and reflect on their implications for adaptation research policy.

One widely acknowledged barrier to knowledge accumulation in the adaptation domain is the lack of consistent use of precise terminology (Hofmann et al. 2011; Wolf et al. 2013). Indeed, persistent confusion regarding key terminology in climate change adaptation constrains the ability of research to address stakeholders' needs (Kiem and Austin 2013) and even limits the effective use of climate information (Lemos et al. 2012). In overcoming terminological confusion, a particular strength of our approach has been in-depth and iterative interaction with the case study teams in order to understand their criteria for selecting solution-oriented research questions and methods to address them. This allowed us to more precisely and consistently describe research questions and methods across numerous cases than is typically done in the literature. The terminology used here was developed through these interactions and provides a coherent framework to synthesise cases applying different solution-oriented methods (see also Hinkel and Bisaro 2014).

The analysis allows us to draw conclusions regarding which individual methods should be further developed. Specifically, we present observations on the development of both impact analyses, economic analysis and other social science approaches and the contexts in which each are salient. Further, based on analysing sequences of methods, we formulate general recommendations for the design of transdisciplinary adaptation research processes, which themselves consist in sequences of multiple methods.

The paper is structured as follows. In the next section, we introduce the MEDIATION project and the methods we have applied in developing the analysis and synthesis of cases presented in this paper. In "Results" section, we present results in form of the methods applied in the

MEDIATION cases, their strength and weaknesses, and the patterns identified in the sequences of methods applied in the cases. In "Discussion: adaptation research methodologies" section, we discuss the implications of our results section for adaptation research methodologies. "Conclusions: implications for adaptation research policy" section concludes.

Materials and methods

The MEDIATION project

MEDIATION was an EC-funded project that ran from 2010 to 2013 with the objective of advancing adaptation in Europe through solution-oriented adaptation research. The project aimed to advance adaptation at range of scales and in different sectors in Europe through a case study approach. This work is reported on in a series of case study papers (see Carter et al. 2014; Holman et al. 2014; Khabarov et al. 2014; Tainio et al. 2014; van Slobbe et al. 2014; Varela-Ortega et al. 2014; Werners et al. 2014; Zhu et al. 2014).

The project further aimed to address the fragmentation of knowledge and methods in climate change adaptation research and practice by developing solution-oriented methodological guidance on adaptation transferable across different contexts. To this end, the project developed a diagnostic framework for solution-oriented adaptation research that supports the selection methods appropriate to a given adaptation challenge. The framework was developed through analysing the choice of methods by both case study researchers in MEDIATION and the wider adaptation literature and is reported on in Hinkel and Bisaro (2014).

The present paper complements the methodological guidance developed in Hinkel and Bisaro (2014) by describing, analysing and synthesising experiences with methods in the individual cases. The analysis and synthesis presented in this paper are based on the following cases.

Three cases were conducted at a regional level:

- *Forest fires in Europe* Khabarov et al. (2014) assess forest fire risk and adaptation options in three regions of Europe.
- *Rhine salmon and shipping policy* van Slobbe et al. (2014) appraise climate risks and adaptation options with respect to salmon restoration policy and shipping in the Rhine river.
- *Nordic elderly* Carter et al. (2014) appraise climate-related health risks for elderly people in three Nordic countries.

Another six cases were carried out at national and sub-national levels:

- *Finnish biodiversity* Tainio et al. (2014) analyse climate change impacts on butterfly habitat in Finland and appraise adaptation options.
- *Agriculture in the Guadiana* Varela-Ortega et al. (2014) analyse water use, crop yields and adaptation options in the Spanish Guadiana river basin.
- *Agriculture in Serbia* Bisaro et al. (2013) analyse the institutional context for adaptation options addressing drought risks in agricultural in Serbia.
- *Tuscan wine production* Zhu et al. (2014) analyse climate change impacts on wine production in Tuscany.
- *Wadden Sea flood protection and nature conservation* Werners et al. (2014) analyse flood protection and conservation policy in the Dutch Delta Programme.
- *Cross-sectoral adaptation in Scotland* Holman et al. (2014) analyse cross-sectoral impacts and robust adaptation policy options together with Scottish stakeholders using CLIMSAVE (Climate Change Integrated Assessment Methodology for Cross-Sectoral Adaptation and Vulnerability in Europe) platform.

The MEDIATION cases thus provide a broad survey of typical adaptation challenges faced by stakeholders and researchers in Europe across different geographical settings, levels of governance and sectors. The cases reflect the growing diversity of adaptation challenges and methods facing stakeholders in Europe, which allowed us to develop a wide overview of adaptation challenges and methodological issues for adaptation research in general.

Data collection and analysis

For the nine case studies listed above, we collected data through iterative interaction with the case study researchers. In each case, the case study teams consulted with stakeholders in order to identify research questions salient to decision-makers. The case study teams then selected methods to address these questions based on their own expertise and knowledge of the case setting.

For each case, we administered questionnaires to case study teams on the research question they addressed, their criteria for choosing the research question, the methods they applied, their criteria for choosing methods and the results they achieved. Initial data gathered through the questionnaires were then supplemented and refined through in-depth discussion with case study researchers and wider discussion amongst the project team at biannual meetings. We were thus able generate detailed data on methods applied and criteria for choosing methods.

The iterative process of data collection was important, as knowledge regarding criteria for identification of research questions and methods is often tacit, and the researchers needed to be made sensitive to the language

developed in order to make these criteria explicit. This iteration allowed us to develop more precise labels for the research questions and methods in the cases, and test and refine these labels as we went along (see Table 1). Moreover, whereas adaptation cases studies typically report on one research question, the MEDIATION cases iteratively addressed sequences of questions. This allowed us to analyse patterns in the sequences of questions addressed and methods applied. The cases are summarised in Table 1 below. For more extensive description of the cases and the questionnaire data used to develop the labels, see Appendix I.

Results

Overview

Table 1 gives an overview of the nine case studies conducted in MEDIATION in terms of the salient research questions addressed, class of question, methods applied and results. Methods are classified according to the class of question they address and thus fall under three high-level classifications: analysing impacts, understanding collective action and appraising adaptation options. In the following subsections, we describe the methods in greater detail. In particular, we discuss the strengths and weaknesses of methods in addressing its associated class of research question.

In the following subsections, we discuss the methods applied in the cases, first, for each of the three classes of questions separately ("Analysing impacts" to "Appraising adaptation options" sections) and then for the full sequences of questions addressed in a case. We are not able to discuss every method presented in Table 1 for reasons of space. Instead, we select illustrative examples, focussing on those methods that have been newly developed in the project or represent relatively new applications for adaptation research.

Analysing impacts

Table 2 shows the methods applied to analysing impacts in all of the MEDIATION cases and summarises their strengths and weaknesses. While nearly all cases applied methods aimed at analysing impacts, we discuss only two cases covering sectors in which impact analysis is relatively less developed. Khabarov et al. (2014) quantify adaptation options addressing forest fire risk in Europe, while Carter et al. (2014) conduct a spatially explicit vulnerability analysis for the elderly in northern Europe. Three different methods for analysing impacts were applied in the two cases namely, impact projection, impact attribution and vulnerability and capacity indication.

Cases in which impact analysis has been explored through existing impact models, such as in the agricultural sector, i.e. Guadiana (Varela-Ortega et al. 2014), or where impact analysis was mainly an input to other methods, i.e. Rhine (van Slobbe et al. 2014), Tuscany (Zhu et al. 2014), Finland (Tainio et al. 2014) and Scotland (Holman et al. 2014), are discussed in later sections.

Modelling forest fire risk in Europe

Addressing forest fire risks and adaptation options, Khabarov et al. (2014) developed and calibrated a standalone fire model (SFM) for projecting climate change impacts and adaptation options with respect to forest fire risk in Europe. A proxy for fire suppression potential was derived at the country level based on empirical observations from the European Forest Fire Information System and Global Fire Emissions Database. Adaptation was thus disaggregated into national level response potential. The calibration with observed data on burned area revealed good agreement at the national level. The team then applied the model to estimate the residual impacts of two adaptation options—prescribed burning (preventive) and fire suppression (reactive)—at a regional scale. They found that forest fire risk could increase by 200 % by 2090. Each adaptation option can significantly reduce this, keeping the increase in risk to under 50 % from the current situation by 2090.

Vulnerability of the elderly in Nordic countries

Addressing the question of future climate risks for the elderly in Nordic countries, Carter et al. (2014) develop a method for assessing the vulnerability of the elderly to weather extremes under climate change. A vulnerability index composed of exposure indicators and adaptive capacity indicators was developed. The exposure indicators consist in projections of key climate variables describing heat-related extreme events (e.g. change in number of high-temperature days) and cold-stress-related events (e.g. icy conditions), and elderly population. The adaptive capacity indicators consist in socio-economic variables, such as elderly welfare recipients, elderly living alone and the number of health care workers in an area. Upper and lower bounds for values of the adaptive capacity indicators are projected out to 2,030. The exposure and adaptive capacity indicators are presented through an interactive web-based mapping tool, which allows the user to assign various weightings to the different indicators. The indicators are thus combined into an index of current and future vulnerability of the elderly.

Table 1 Overview of salient research questions identified and methods applied in the MEDIATION cases

Case	Salient research question	Class of question	Method	Results
Forest fire risk in Europe	1. What are the potential impacts of climate change on forest fire risk in Europe?	Analysing impacts	Potential impact projection	Forest fire risk could increase by 200 % by 2090
	2. What are the impacts of climate change and adaptation options on forest fire risk in Europe?	Analysing impacts	Residual impact projection	Adaptation can reduce increase to under 50 %
Rhine salmon and shipping	1. What are key impacts of climate on salmon populations and shipping in the Rhine?	Analysing impacts	Potential impact projection	Increase days with high temp., and low flow
	2. What are the adaptation turning points, i.e. thresholds for sociopolitical objectives?	Analysing impacts	Potential impact projection	High risk to exceed 27 °C temp. and low flow after 2,050
	3. Which adaptation option should be chosen?	Appraising adaptation options	Robust decision-making	Schematic adaptation pathways
Nordic elderly	1. In which regions are elderly likely to be vulnerable to climate change?	Analysing impacts	Vulnerability indication	Spatially explicit projections of exposure and adaptive capacity
			Impact attribution	Statistical relationship between temp. and excess mortality
Finnish biodiversity	1. What are the potential impacts of climate change on grassland biota in northern Europe?	Analysing impacts	Potential impact projection	Spatially explicit habitat shifts
	2. What are the measures for enhancing populations of these species?	Understanding collective action	Institutional analysis	Agri-environmental measures
	3. What are the impacts, including costs, of the adaptation options?	Analysing impacts	Residual impact projection	Costs for adaptation option in each scenario
	4. Which adaptation option should be taken?	Appraising adaptation options	Robust decision-making	Translocation and dispersal corridor are robust options
Agriculture in the Guadiana basin	1. How will climate change affect water availability, crop yields and crop water requirements?	Analysing impacts	Potential impact projection	Decreasing water, crop yields
	2. How will climate change affect land use and farmers' income in the Guadiana basin?	Analysing impacts	Residual impact projection	Shift to crops with low water needs. Increased aggregate income
	3. What are the adaptation policies and perceived policy needs at the different levels of governance?	Understanding collective action	Institutional analysis	Lack of finance and enforcement mechanisms for adaptation
	4. Which are the main actors/institutions involved in adaptation and how are they linked?	Understanding collective action	Institutional analysis	Description of stakeholder networks
	5. Which options are preferred by stakeholders?	Appraising adaptation options	Deliberative decision-making	Improving water efficiency and changing crop varieties
Serbian agriculture	1. What constrains farmer investment in irrigation?	Understanding collective action	Institutional analysis	Farmers do not register due to tax implications
	2. What is the most cost-effective option? (Appraising adaptation options)	Appraising adaptation options	Deliberative decision-making	Finance and insurance provision options preferred

Table 1 continued

Case	Salient research question	Class of question	Method	Results
Tuscan wine production	1. What are the potential impacts of climate change on grape yield in Tuscan?	Analysing impacts	Potential impact projection	Reduced favourability for current varieties at current elevations
	2. What are the impacts of climate change on wine production in Tuscany under several adaptation options?	Analysing impacts	Residual impact projection	Changing grape varieties and elevation can maintain productivity
	3. Which option should be chosen?	Appraising adaptation options	Deliberative decision-making	Genetic selection of current varieties
	4. What are the indirect outcomes of winemaking to tourism in Tuscany?	Analysing impacts	Valuation	Landscape diversity has high aesthetic value
Wadden Sea flood protection and nature conservation	1. What are long-term climate change impacts in the Wadden Sea?	Analysing impacts	Expert consensus	List of key impacts
	2. What are promising strategic options to adapt to climate change?	Appraising adaptation options	Robust decision-making	Schematic adaptation pathways
Cross-sectoral adaptation in Scotland	1. What are the key climate change impacts in Scotland?	Analysing impacts	Residual impact projection	Flood exposure will increase in some areas, while forest cover will decrease
	2. What is the preferred adaptation option?	Appraising adaptation options	Robust decision-making	"People-based" adaptation option performs best across sectors and scenarios

Methods classified based on Hinkel and Bisaro (2014)

Table 2 Strengths and weaknesses of methods applied for analysing impacts

Case	Method	Description	Strengths	Weaknesses
Forest fires in Europe	Residual impact projection	Downscaled GCM input to standalone fire model (SFM) run for active suppression and prescribed burning adaptation options	SFM reproduces observed burned area at national level	Range of modelled options limited
Nordic elderly	Vulnerability and capacity indication	Indicators of vulnerability to weather extremes with user interface	Users inform choice and weight indicators	Lack of theory for indicator weighting and aggregation
	Impact attribution	Statistical model relating excess mortality and temperature	Supports projecting future impact	High uncertainties due to data gaps
Finnish biodiversity	Impact projection	Bioclimatic envelope modelling (BEM) for butterfly indicator species driven by 11 climate scenarios)	Spatially explicit impacts useful for planning	High variation in suitable areas for different models and scenarios
Rhine salmon and shipping	Potential impact projection	Water discharge and temperature models forced by GCMs and critical water temperature limits for salmon	Identification of timing of key low-flow turning points	Socio-economic development not included
Agriculture in the Guadiana	Residual impact projection	Downscaled GCM input to hydrological (WEAP) and crop yield model combined with economic optimisation of farm decisions	Identification of timing of key impacts (e.g. water supply shortfalls)	Does not include institutional and cognitive variables
Tuscan wine production	Residual impact projection	Downscaled GCM input to grapevine model with optimisation of farm inputs and distribution under different adaptation options	Identification of timing of key impacts (e.g. yield reduction)	Does not include institutional and cognitive variables
Cross-sectoral adaptation in Scotland	Residual impact projection	ClimSave integrated assessment platform applied to explore residual impacts in several sectors for different scenarios in Scotland	Visualisation of key impacts in a range of scenarios	Analysis only at national scale; cannot include "soft" options

Strengths and weaknesses

Potential impact projection is useful for analysing risks and key thresholds, while residual impact projection is useful for understanding the costs and benefits of adaptation options.

Difficulties arise in projecting residual impacts when "autonomous adaptation" is not well understood. In particular, in sectors where market signals are not as important, economic optimisation may not be a realistic assumption for modelling adaptation. Instead, adaptation may depend on a number of cognitive and institutional variables, and these are often not well understood (Patt et al. 2010). A weakness of residual impact projection methods is thus that not all relevant adaptation options may be modelled particularly when autonomous adaptation is not well understood. For instance, the proxy for response potential developed by Kharbarov et al. (2014) was constrained the scope of options considered due to the method's limitations in modelling land fragmentation, species change and behavioural change.

When impact models are not available, statistical models can be built through impact attribution methods. Impact attribution methods are, however, highly dependent on data availability. In the Nordic elderly case, for instance, the case study team also carried out a regression to identify the statistical relationship between mortality and regional average daily temperature (Carter et al. 2014). However, difficulties in obtaining data for the same set of variables across the entire study region limited the number of explanatory variables considered to temperature-related variables only (see Appendix 1 in ESM). Impact attribution using statistical methods must be treated with caution when data availability for many relevant variables is limited.

When data on observed impacts are limited, an alternative to building statistical models is to develop vulnerability and capacity indicators to analyse impacts. Carter et al. (2014) develop such a method in the Nordic elderly case. Indicators can be selected based on existing literature. For instance, the literature on geriatric health proposes a number of factors—labelled either "sensitivity" or "adaptive capacity" in the climate change literature—that influence health outcomes for the elderly during weather extremes. A weakness of the method is, however, that aggregating indicators into vulnerability indices is often subjective and difficult to defend scientifically (Hinkel 2011). To address this issue, Carter et al. (2014) allow stakeholders to make this aggregation themselves through a web-based tool; thus, the aggregation and weighting are transparent and in principle based on the local knowledge of stakeholders.

Understanding collective action

Two cases applied methods aimed at understanding collective action for adaptation. Table 3 summarises these methods and their strengths and weaknesses. In both the Guadiana (Varela-Ortega et al. 2014) and in Serbia (Bisaro et al. 2013), adaptation options involved the provisioning of public goods by private actors, i.e. through managing a shared aquifer and restoring a shared irrigation system, respectively.

Water scarcity in the Guadiana river basin, Spain

In the Guadiana basin, farmers make use of a groundwater aquifer, which also maintains an internationally significant wetland. Reducing pressure on the aquifer is an important consideration in adapting agricultural production to increasing drought frequency. Adaptation options involve groundwater extraction from the shared aquifer, and private actors are thus interdependent (Varela-Ortega et al. 2014). Adaptation measures, such as regulation or market-based instruments, to improve the technical efficiency of water management require collective action for effective monitoring and enforcement. Social network mapping techniques were applied to identify linkages and gaps between key organisations for adaptation. This analysis complemented impact projections by identifying potential barriers and communication gaps between key actors to be addressed in the implementation phase.

Drought impacts on agriculture in Serbia

In central Serbia, increasing drought impacts threaten the agricultural production of small-holder farmers. Irrigation canals are in poor condition following fragmentation of the land base during the post-communist transition. The restoration and maintenance of the irrigation system, which require collective action due the shared nature of the irrigation canals, can effectively reduce impacts of current climate variability and future change (Bisaro et al. 2013). Therefore, understanding institutions in supporting and constraining collective action gives rise to salient research questions. The case study team carried out semi-structured interviews and workshops in order to identify key institutions in the irrigation system. They found that institutions affecting farm registration and property taxes are key constraints to irrigation canal restoration. However, due to time and resource constraints, more in-depth institutional analysis was not carried out.

Table 3 Strengths and weaknesses of methods applied for understanding collective action

Case	Method	Description	Strengths	Weaknesses
Agriculture in the Guadiana	Institutional analysis	Participatory workshops for socio-institutional network mapping	Promotes shared understanding of institutional context	Too brief for understanding informal institutions
Serbian agriculture	Institutional analysis	Semi-structure interviews for institutional analysis	Identifies institutional barriers	Too brief for understanding informal institutions

Strengths and weaknesses

A strength of these methods is that analysing collective action can complement impact analysis by providing a more comprehensive picture of possible adaptation options through understanding individual and group incentives and norms, rather than strictly identifying ideal or optimal options (Tompkins and Eakin 2012). Such a focus on institutions represents a shift from identifying adaptation measures through lists or inventories to a more explicit focus on collective action problems (March and Olsen 1989) or social dilemmas (Ostrom 1990). For instance, in the Serbian case, the potential for reform of the land registration and taxation was identified as a means to advance adaptation, which would not typically be considered in impact analysis methods.

In both of these cases, however, social science analysis was limited by time constraints and the disciplinary backgrounds of the case study teams. Planned interactions were limited to 1–2 workshops so as not to overburden stakeholders. Further, the case study teams included social scientists trained either as economists or in participatory methods. More in-depth institutional analysis may require both longer periods of study and the inclusion of a wider range of social science disciplines, such as political science, sociology, psychology and anthropology.

Appraising adaptation options

Several cases applied methods for appraising adaptation options. Table 4 shows the methods applied for appraising adaptation options in all of the MEDIATION cases and summarises their strengths and weaknesses.

Each of the cases discussed in this section involved appraising adaptation options with long time horizons. When adaptation decisions involve at least one long-term option, standard cost–benefit analysis using net present value is inadequate. This is because climate and socio-economic scenarios are required to compute outcomes over longer time horizons, and in principle, probabilities cannot be meaningfully assigned to different scenarios. Such probabilities are, however, necessary in order to calculate the net present value of an option (Hallegatte 2009).

Two different methods were applied to address uncertainties involved in appraising long-term adaptation options. In several cases, formal robust decision-making methods (Lempert and Collins 2007), e.g. adaptation pathways (Haasnoot et al. 2012), were carried out. Robust decision-making methods appraise options in terms of their effectiveness over a wide range of scenarios (Lempert and Schlesinger 2001; Wilby and Dessai 2010). The adaptation pathway approach extends the classical one shot robust decision-making approach by considering multiple-shot adaptation decisions and appraising options in terms of their flexibility to change to a different strategy in the future. Adaptation pathways are combinations of measures that avoid crossing a key impact threshold (Haasnoot et al. 2012).

In other cases, deliberative decision-making methods were applied. Deliberative approaches involve stakeholders directly in the appraisal by harmonising preferences and/or eliciting information. When combined with appropriate modelling tools, they make participants aware of key uncertainties and may enable the development of a consensus on the relative importance of different outcome attributes (Renn 2008).

Grassland biodiversity in Finland

In Finland, grassland biodiversity is threatened as habitats will shift due to climate change and species dispersal corridors risk being closed off by agriculture intensification. Tainio et al. (2014) conduct a robust decision-making appraisal of options to conserve key butterfly species under climate change. Adaptation options include maintenance of dispersal corridors and translocation of grassland species. The authors used a bioclimatic envelope modelling approach to project habitat change for butterfly indicator species under 11 scenarios of future climate change at a spatial resolution of 2-km grid cells. The team also used surveys to derive cost information on the adaptation options and assessed their cost-effectiveness under future climate change. Because of high variation in climatically suitable habitats across different models and scenarios, an evaluation of the costs and benefits for each site across all scenarios and model combinations was necessary for a

Table 4 Strengths and weaknesses of methods applied for appraising adaptation options

Case	Method	Description	Strengths	Weaknesses
Finnish biodiversity	Robust decision-making	Cost-effectiveness analysis of options for all scenarios using bioclimatic envelop modelling	Supports identification of robust options (e.g. portfolios)	Resource intensive
Wadden Sea Rhine salmon and shipping	Robust decision-making	Qualitative adaptation pathways appraisal using inventory of adaptation measures and key adaptation turning points	Encourages planning in advance of turning points	Not precise enough for infrastructure planning
Agriculture in the Guadiana Tuscan wine production	Deliberative decision-making.	Stakeholder ranking options via analytical hierarchy process (AHP)	Supports structured comparison of complex options	Requires intensive stakeholder engagement
Scotland cross-sectoral adaptation	Robust decision-making	ClimSave integrated assessment platform applied to compare options across a range of scenarios	Enables comparing options across all scenarios	Evaluates only "archetypical" options

comprehensive robust decision-making appraisal. They found that species translocation was the more cost-effective option within each scenario. The authors find that the approach could be further developed to construct portfolios of dispersal corridors as robust options.

Low-level flow thresholds in the Rhine

van Slobbe et al. (2014) analyse future impacts of low-flow events in the Rhine river basin. Low-flow events may negatively affect Rhine salmon restoration policy and shipping. Salmon are not able to migrate or even survive at higher water temperatures, which increase during low-flow events, while shipping is limited by low water levels in the river. Daily transient water temperatures and flow rates were projected at key points in the Rhine for the twenty-first century using several scenarios and downscaled GCMs. The authors find key turning points between 2,070 and 2,100, when policy objectives will no longer be attainable if no adaptation action is taken. They assemble an inventory of adaptation measures, classified according to how long they are able to delay the crossing of an important turning point.

Chianti wine production in Tuscany

In Tuscany, the Chianti region is facing increasing temperatures and changing rainfall patterns, which may lead to the need to change vineyard locations or grape variety. However, the Tuscan landscape aesthetic and tourist appeal derives largely from wine production, which is also considered part of the cultural heritage of the region (Trombi et al. 2013). Thus, indirect outcomes are an important consideration in choosing adaptation options for wine production. Zhu et al. (2014) applied the analytical hierarchy process (AHP) in order to elicit a quantitative evaluation of different adaptation options from different stakeholder groups (e.g. private Chianti producers or public decision-makers). The AHP is a deliberative multi-criteria analysis method that enables stakeholders to compare options pair-wise over a range of criteria, and also weight the criteria (Saaty 1990). The AHP thus supports deliberative decision-making over options with multiple attributes. The case study team encountered difficulties in achieving broad stakeholder participation due to the time and resources required, and therefore, a web application was developed to allow the remote participation of relevant stakeholders (Trombi et al. 2013). The resulting preferred option of genetic selection of the existing grape variety showed that flexibility of options was less highly valued by stakeholders, while technical feasibility was considered highly important.

Water scarcity in the Guadiana river basin, Spain

In the Guadiana case, discussed above, Varela-Ortega et al. (2014) also applied the AHP to appraise different water management options, including increasing storage capacity, changing crop varieties and developing an insurance system. The results showed that options of improving the efficiency of water use and switching to new crop varieties were preferred by stakeholders over increasing storage capacity of the system, which was perceived as costly and potentially damaging to the environment.

Strengths and weaknesses

Robust decision-making methods are highly resource intensive, requiring detailed probabilistic information. In MEDIATION they were largely applied to identify key

thresholds, rather than as prescriptive decision-making tools. For instance, van Slobbe et al. (2014) find that the inventory of adaptation measures is useful in the Rhine case for identifying adaptation pathways in a schematic manner together with policy and decision-makers. However, the appraisal of pathways was qualitative due to data and model limitations, and would require much more data to be applied in infrastructure planning. For the Finnish biodiversity case, resource intensity of the method was also a constraint, as a full portfolio analysis was not feasible in the time frame of the study.

Deliberative methods may be an appropriate alternative to robust decision-making methods considering the resource-intensive nature of projecting adaptation options over longer timescales and multiple scenarios. Particularly when adaptation involves public adaptation options, such as, for example, public investments in water storage in the Guadiana, deliberative methods may be more appropriate. Due to the public good nature of such adaptation options, it may be more appropriate to decide on such options using participatory deliberative approaches.

However, it is important to note that, as illustrated in the Tuscan case, deliberative methods bring their own resources requirements. Carefully designed stakeholder engagement is needed, particularly when awareness of climate change impacts is low (Zhu et al. 2014).

Sequences of methods

Beyond analysing the strengths and weaknesses of individual methods, we have also analysed sequences of methods applied in the cases. We observe three general patterns in the sequences of methods. We discuss reasons for each of these patterns, which have been distilled from the data collected from the case study teams (see Appendix 1 in ESM).

The first pattern we observe is that some cases only conduct impact analysis. This is the case for the Forest Fires and Nordic Elderly cases (see Table 1). The reason for this is that a new method had been developed for a sector or issue for which relatively little impact analysis had been done. This meant that the development of the impact model was itself resource intensive. It also meant that the results of the method, e.g. projections of the residual impacts of adaptation options, were not yet considered reliable enough to conduct formal decision-making.

A second sequence observed was that some cases carried out an institutional analysis, in parallel to the impact analysis and economic appraisal. The reason for this was that collective or public goods were to be provided by the adaptation options under consideration, and collection action was thus an important part of adaptation. Therefore, the case study teams considered understanding collective action a salient research question and applied methods aimed at understanding the incentives and norms constituting the institutional context. These cases applied social science methods called for by several authors (Agrawala 2011; Tompkins and Eakin 2012).

A third sequence observed was that of impact analysis followed by formal robust decision-making methods. This sequence was more commonly observed than the sequence involving institutional analysis. The reasons for this were disciplinary constraints, as researchers conducting impact analysis often felt they had a greater capacity to conduct closely related economic appraisal methods, which could use the outputs of the impact analysis already carried out. Further, stakeholders often expressed a preference for economic appraisal of options. A subset of this sequence was the observed pattern of impact analysis followed by deliberative decision-making methods. The reason for this was that formal methods were often seen as too resource intensive in terms of skill, data and time.

Discussion: adaptation research methodologies

Based on the described strengths and weaknesses of individual methods, and sequences of methods observed in the MEDIATION cases, we arrive at three general findings of relevance for adaptation research.

First, *no standard recipe exists for addressing climate change adaptation*. In general in MEDIATION, different sequences of diverse natural and social science methods were applied in each of the cases. This provides support the view that sequences of methods cannot be specified ex-ante. Further, the MEDIATION cases show that not all methods are relevant in every situation. As was seen in the Serbian case, for example, impact analysis is not necessarily a prerequisite for advancing adaptation because behavioural aspects and institutions posed greater constraints to responding to increasing climate risks.

Rather than specifying research questions in a "top-down" manner, solution-oriented adaptation research can benefit from identifying particular adaptation challenges based on stakeholder needs in the adaptation setting. Research questions and methods should be chosen based on the explicit criteria of addressing the salient challenges identified together with stakeholders (Cash et al. 2003).

Further, addressing adaptation should proceed as an iterative learning cycle. Once an adaptation challenge is identified and addressed through either research or practice, new insights are gained or action is taken and the situation is changed. Again, new challenges, research questions need to be identified together with stakeholders in order to choose methods tailored to the specific biophysical, socio-economic and institutional setting.

This "non-standard" and iterative nature of adaptation entails a need for greater flexibility and transdisciplinarity in funding programming to avoid constraining the choice of methods in a particular situation by the disciplinary backgrounds of involved researchers.

Second, *the choice of methods has implications for choosing adaptation options and subsequent adaptation research methods*. While there exists scientific debate about which methods are most salient for adaptation (e.g. Dessai and Hulme 2004; O'Brien et al. 2007; Dessai et al. 2009), this has been largely discursive and few studies have empirically analysed the implications of different methodological choices. Because in MEDIATION different methods were applied to the same situation it was possible to compare the results of different methods.

For example, methods of deliberative decision-making and of institutional analysis were applied to the same situation regarding adaptation to droughts in the agricultural sector in Serbia (Bisaro et al. 2013). On one hand, a multi-criteria analysis decision-making method conducted with national and regional stakeholders gave high rankings to options of regional investments to provide finance and insurance to private farmers. In contrast, institutional analysis methods provided insight into why existing irrigation systems are not collectively maintained or improved. Barriers to collective action were found to arise from disincentives to register farms shaped by the institutional context. The institutional analysis provided complementary information that may not have been available to stakeholders involved in appraising adaptation options, and provided insight on why existing financial instruments, such as, providing grants or loans to farmers had been relatively ineffective.

The example thus shows that choice of methods has implications for the subsequent step in adaptation research. On one hand, choosing a level of investment in finance or insurance would require further information, including climate scenario analysis, on the costs and benefits of doing so. On the other hand, the institutional analysis pointed to the need for agricultural policy to address legislative and procedural barriers through reforming institutions and thus change incentives for collective action amongst farmers for irrigation maintenance.

This example is consistent with the more general observation that adaptation decision-making methods require information on future climate and the costs and benefits of an option and thus are linked to impact analysis methods (see "Sequences of methods" section). Decision-making methods are often not able to include information on the institutional context, e.g. information on norms and values that is not easily quantified. Applying decision-making methods can thus focus the next step in the adaptation process on the need for improving data or models to quantify costs and benefits of adaptation options and to reduce uncertainty in computing outcomes (O'Brien et al. 2007). The affinity between impact analysis and decision-making methods risks too little focus on the institutional context in the design of policy (Dessai et al. 2009).

There is therefore a need for adaptation research policy to support a wider application of social science methods. Institutional analysis can focus the next step in the adaptation process on designing policy fit to the institutional context, addressing barriers arising from that context. The application of social science methods provides a greater focus on institutional aspects shaping motivations and preferences of different actors, and what is needed to understand and overcome social dilemmas.

Third, *formal decision-making methods using multi-scenario, multi-model analysis requires the development 'light-touch' methods.* Improved information on the cost and benefits adaptation options is important for advancing adaptation in many settings. For adaptation decisions with mid to long time horizons, costs and benefits must be assessed over several scenarios and impact models in order to provide reliable information. In the adaptation literature, new approaches to appraising adaptation options are being applied to long-term options, e.g. real-option analysis (Jeuland and Whittington 2014) or portfolio analysis (Crowe and Parker 2008). However, their use thus far has been limited to the water sector and most adaptation studies do not formally compare several options across a range of scenarios (Hunt and Watkiss 2011).

The MEDIATION cases confirm that the high level of data, time and skill required of multi-model, multi-scenario approaches are a barrier to their more widespread application. Most cases apply deliberative decision-making methods to rank options rather than formally comparing options across scenarios and models. In those cases, that did apply multi-model, multi-scenario methods, adaptation options were only represented schematically without enough detail for sub-national planning decisions (see "Appraising adaptation options" section).

Thus, despite the availability of such methods, their use in adaptation decision-making remains limited. It is therefore recommended, following Watkiss et al. (2013), to develop "light touch" versions of such methods, which are less time, skill and resource intensive, to support regional and sectoral adaptation decision-making and to evaluate and prioritise adaptation options. Such simplification should not undermine scientific credibility by ignoring key data and processes, and a proper relationship with the underlying scientific knowledge should be maintained. Communication regarding such methods will require much attention, providing transparent information about the capabilities of the methods and how the results can be interpreted.

Conclusions: implications for adaptation research policy

This paper has analysed nine solution-oriented adaptation research cases carried out in the MEDIATION project. The underlying rationale of case study selection was to reflect the wide diversity of adaptation challenges and methods currently confronting adaptation researchers, policy-makers and stakeholders. The discussion on research questions, methods and results in each case provided a survey of the methodological state-of-the-art in adaptation research in Europe.

It is important to emphasise once again that our synthesis of these cases was based on in-depth and iterative interaction with the case study teams in order to more precisely describe research questions and methods applied. This enabled us to describe sequences of methods applied in the cases and identify patterns therein. We have thus systematically analysed methodological choices and the effectiveness of these choices, something that has been lacking in the adaptation literature.

The major findings of this paper are that, first, that even though social science methods are often indicated, they are often not applied. One of the main patterns observed is the link between impact projection and formal decision-making methods. A cautionary note for the design of adaptation research policy and projects is therefore warranted. This link can overshadow behavioural and institutional analysis methods, which may provide more salient insight, e.g. for the design policy instruments. Institutional and behavioural research should therefore be further emphasised to complement economic appraisal methods. It is worth pointing out that these points echo critiques of development planning for over-reliance on economists to the exclusion of wider social science perspectives (see Fine 1999) and thus provides further grounds to be addressed by adaptation research policy.

Second, even when social science methods are applied, in the transdisciplinary settings that characterise adaptation research, it is often within a time frame more constrained than that in a typical disciplinary social science methodological approach. For instance, there is often limited scope for the extensive desk study of historical institutionalists (e.g. Capoccia and Kelemen 2007) or the in-depth qualitative interviews of sociologists, anthropologists or other institutionalists (e.g. Mosse 2006).

Moreover, including social scientists more centrally in transdisciplinary adaptation projects may require some adjustment in the design of stakeholder engagement because for in-depth behavioural and institutional analysis, 1- to 2-day workshops are not sufficient. While such workshops are important for collective decision-making, they are more accurately labelled action research. Social science research may need longer time commitments from researchers and stakeholders and thus also gives rise to its own set of barriers. Thus, an important consideration for adaptation research policy is the (re)-design of incentives for both stakeholders and researchers, e.g. beyond the peer review publication, to engage in these processes, which are time-consuming and do not have a guarantee of success.

This brings us to our final remark, namely that effective stakeholder engagement remains a fundamental issue. Over the last years, an often repeated principle in adaptation research is that stakeholder engagement is essential at all stages and all levels. However, it is clear from the case experiences that this is not a panacea, and stakeholder engagement may lead to its own problems in terms of lack of awareness and is itself resource intensive in terms of design and implementation. A careful consideration of the decision-making context, including the levels of awareness and interest in adaptation, can play an important role in designing more effective stakeholder engagements, as well as identifying situations in which engagement is unlikely to be effective. The level and format of stakeholder engagement can and should differ between different adaptation situations. We would argue that making progress on this issue involves a systematic analysis of the quality and effectiveness of stakeholder involvement to date, an activity that can be supported with the use of a more differentiated terminology for adaptation challenges and methods, such as developed in MEDIATION.

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