MEDIATION Delivery Report

Title	Report on review of cross-sectoral impact of decisions and types of problems and contexts in which different dimensions of uncertainty play a role: *An exploration of tipping points in climate policy responses*
WP Number	1
WP Leader	Sukaina Bharwani
Delivery number	1.2
Relative task(s)	1.1, 1.2
Involved beneficiaries	IIASA, WUR, ECF
Author(s)	Stefan Pfenninger, Saskia Werners, Jochen Hinkel, Anthony Patt
Related to deliverable number(s)	
Date of completion	31 January 2011
Submission Date	
Approved by the WP Leader[1]	

To complete by the Coordinator

Approved by the Coordinator[1]	
Listed[1]	

[1] Date and signature / initials

MEDIATION Deliverable 1.2 — Report on review of cross-sectoral impact of decisions and types of problems and contexts in which different dimensions of uncertainty play a role

An exploration of tipping points in climate policy responses

Stefan Pfenninger (IIASA), Saskia Werners (Wageningen University and Research Center), Jochen Hinkel (European Climate Foundation) and Anthony Patt (IIASA)

ABSTRACT – Adaptation to climate change is becoming increasingly necessary, with potentially severe climate-induced changes still ahead. Of key relevance for decision-making is the potential existence of points in time where the decision situation changes from one type to another because an impact threshold is exceeded. Such a change in the decision situation is, for instance, when the decision shifts from being the concern of one actor or agency to multiple actors at multiple scales. We call these points adaptation crossroads. Their existence has important implications for adaptation decision support because they are where strategic and transformational adaptation decisions will have to be considered. We present three cases to explore adaptation crossroads and look at the implications for scientific decision support. We draw some first conclusions, present a typology of adaptation crossroads, and lay groundwork for further inquiries into this area.

1 Introduction

Adaptation has become an integral part of climate change policy (Adger et al. 2007). In Europe, however, adaptation has not been seen as a significant challenge so far. The current state can be summed up by three main observations (Biesbroek et al. 2010; Pfenninger et al. 2011). First, there is a beginning of strategic planning both at the EU level and in many EU member states, most often in the form of national adaptation strategies. Second, the state of policy and thinking is different across EU member states. Third, adaptations already take place in a variety of settings, but are mostly limited to incremental changes and tweaks within existing management paradigms. This "change at the margins" (Dovers & Handmer 1992) may not be sufficient for future adaptation to more pronounced climate change impacts.

Some adaptation is necessary already because of warming caused by past emissions[2], but the scale of the challenge will be largely defined by the speed and extent of future decarbonization. The goal of limiting overall global warming to no more than 2°C above pre-industrial levels (usually equated with a stabilized concentration of 450ppm CO_2) is supported by more than one hundred countries (Meinshausen et al. 2009). At the same time, many climate scientists see a concentration of 350 ppm CO_2 as a safe long-term boundary (Rockstrom et al. 2009; Hansen et al. 2008)—a boundary that we have already crossed. In any case, current commitments in international negotiations are insufficient to stay below the 2°C target (Climate Analytics 2010). This means that planners should prepare for the climate targets being overshot with a temperature rise of 4°C or more (Parry et al. 2009). Adaptation to such conditions would be challenging at best (Smith et al. 2011), and may face practically insurmountable physical limits in many places due to loss of ecosystem services and interacting impacts (Warren 2011). Furthermore, the possibility of triggering sudden tipping points in the climate system rises with temperature (Kriegler et al. 2009); such tipping points could cause severe and largely irreversible changes (Lenton et al. 2008), which in turn will require reactions quite different from the ones needed to deal with slower, more gradual change.

The notion of tipping points has arisen in the climate discussion with respect to Earth systems, but it may also be relevant as a feature of the social systems within which adaptation policies play out. We focus on adaptation decision situations, and on points where the choice set or optimal strategies of decision-makers change fundamentally, or tip. While the phrase "adaptation tipping points" is attractive, we call them "adaptation crossroads" in this paper, to differentiate them from tipping points in the climate system, and to thus avoid confusion. The

[2] And, in some cases, because of existing climate variability.

idea of a crossroads underscores that there can be an opportunity in these changes, not just a danger, and that active choices are possible, not only passive observation.

When people find themselves at an adaptation crossroads, appropriate decision support is particularly important because of the uncertain nature of future climate change. If this decision support is to be tailored to the problems that adaptation will increasingly bring to the forefront, it has to be sensitive to adaptation crossroads. This leads to two questions. First, is there evidence for adaptation crossroads playing a role in the past or in current decision situations? Using a historical case study approach, we suggest that the 1930s Dust Bowl in the United States had adaptation crossroads-like features, and the example of coastal management in the Netherlands shows adaptation crossroads beginning to play a role in current decision making. Second, what implications do the existence of these crossroads have on the design and provision of decision support? Again taking a case study approach, we examine the two examples of winter tourism in the Alps and coastal protection in the Netherlands.

This report has two objectives, first, to explore the notion of adaptation crossroads and build a basis for further work, and second, to identify key implications of adaptation crossroads for science-based decision support. The MEDIATION Description of Work asks this deliverable to perform a *review of cross-sectoral impact of decisions and types of problems and contexts in which different dimensions of uncertainty play a role*. That is a very broad definition of the types of problems adaptation policy faces. By exploring the notion of crossroads in adaptation decision-making, we intend to bring together the most important aspects encompassed in that description and underlying the intention behind this deliverable, in order to contribute to the design of a common platform to support adaptation.

After introducing the concept of adaptation crossroads and the relevant aspects of decision support in more detail, we present the three cases. We then discuss the implications of adaptation crossroads and based on the common factors in the cases, present an attempt to draw out some properties of such points. We conclude that more work will be needed in various sectors and geographical regions to determine where potential adaptation crossroads could emerge.

2 Background

2.1 Adaptation crossroads

We define adaptation crossroads as impact thresholds beyond which an adaptation decision situation changes qualitatively from one type to another. The decision situation, and the nature of the qualitative change it undergoes, can be defined by such characteristics as the number and type of actors involved in the decision, the scale of the system their decision affects, and the range of impacts on that system their decision has. How exactly this change can be characterized remains, to an extent, an open question, and part of this work is an attempt to further develop the concept. The threshold is reached by a social or ecological variable driven by climate change. Adaptation crossroads therefore are confined to areas where climate change plays a role in the changes to the socio-economic system and can be seen as a specific subset of the wide range of possible social tipping points. This concept of adaptation crossroads is akin to the definition of adaptation tipping points as points where the current management approach fails (as defined by Kwadijk et al. 2010), but it focuses on the decision and its context.

The impact variables driving the adaptation crossroads can be changing slowly and incrementally, or may themselves be subject to a critical and rapid shift (i.e. a climate system tipping point), and so are not necessarily associated with natural (climate) system tipping points. First, an adaptation crossroads can be driven by a climate variable (e.g. sea level or annual snowfall) that does not itself tip. Second, an adaptation crossroads will additionally be dependent on social values or economic priorities (Adger et al. 2009), such as a defined limit of what cost is acceptable at most for coastal defense. For instance, building higher dikes is technically feasible and currently socially desirable in many coastal defense situations.

However, future social priorities and economic costs could mean that decisions are taken to retreat from the coast in some areas. The shift from the decision of how high to build the dikes, to how far to retreat, would be a crossroads. Another example of an adaptation crossroads would be when the problem shifts from being the concern of one actor at the local scale, to many actors at the subnational or higher scales. At the same time, a problem might also shift from one sector to another or several others, particularly when changes in economic activities are required (Figure 1).

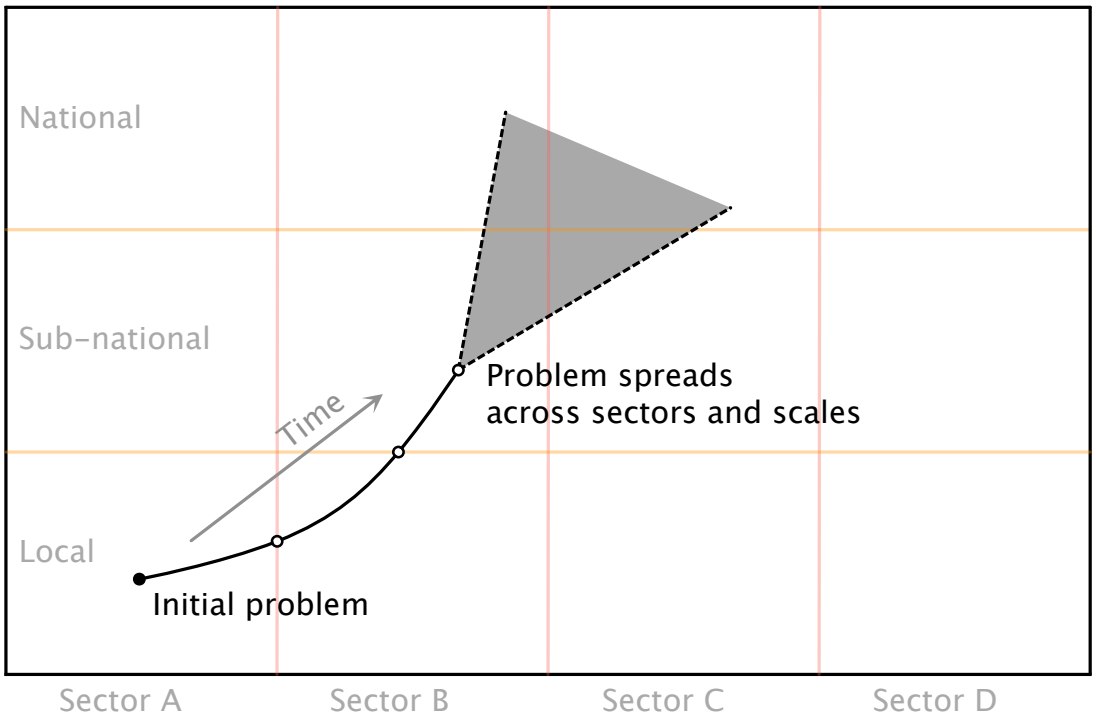

Figure 1: Problem shift across scales (vertical axis) and sectors (horizontal axis), an illustration of one type of adaptation crossroads.

A key objective for policy-making would be to identify adaptation crossroads in advance, in order to ease the transition they necessitate. This is where scientific decision support plays a role, which is detailed further in the next section. One way of advance identification is by starting from the current management approach and trying to determine how robust to future impacts that approach is, i.e., at what point in time it will fail given specific climate projections (Kwadijk et al. 2010). This is a different paradigm than starting from the expected future impacts. The problem with a focus on impacts is that such studies can suffer from an "explosion" of uncertainty, resulting from the need to calculate a cascade of events (Dessai & van der Sluijs 2007). Reducing uncertainty in climate projections is impossible, thus one can argue that they should not form the exclusive basis for decision-making (Lemos & Rood 2010). Moving from scenario-led (top down) to an approach that puts adaptation options appraisal or a "risk-of-policy" approach at the core is seen in literature as a useful alternative (Lempert et al. 2004; Wilby & Dessai 2010). Widening the focus to include vulnerability is another way to move beyond exclusively looking at impacts. But the uncertainty goes further than climate model uncertainty: in many instances, it is not even clear what kind of decisions have to be taken if the problem involves many actors at different levels of decision making. This ambiguity, like uncertainty, requires specific efforts to be dealt with effectively (Brugnach et al. 2011). Identifying adaptation crossroads could reduce this ambiguity about the decision environment.

One can divide adaptation into two distinct levels: changes to management unit decisions, and changes to the decision environment and policy objectives themselves (Howden et al. 2007). After identification of an adaptation crossroads, decision-making needs to generate new

options and search for strategic alternatives on the latter level. Identifying an approaching crossroads would "buy time" to develop strategies for those changes, while in the meanwhile regular management unit decisions can be made for incremental adaptation. Even if a crossroads is not identified, or it is identified without steps taken to avoid it, the transformation itself might not be dramatic. It could be gradual even though the dynamics of the system have already changed, so that a new equilibrium will slowly be reached (Walker & Meyers 2004). Similar to the irreversibility seen in climate system tipping points, going back to the state before the crossroads may no longer be possible on a conceivable timeframe, even in such cases where the change itself is slow.

Although the pressure and increasing urgency of climate change are a new challenge for public policy, there are many existing bodies of work that can be drawn on to understand and manage the transitions that will take place at adaptation crossroads.

The idea of a shift from incremental to transformational (rapid, or dramatic) change has been a theme of social and natural science for some time and is not in itself new: for instance, it is a central aspect of resilience thinking (Folke 2006), and appears in evolutionary biology as the idea of punctuated equilibria, an idea then taken up by policy studies (Eldredge & Gould 1972; Baumgartner & Jones 1993). Sociology also has a body of literature on social change that could contribute to the understanding of adaptation crossroads (Nisbet 1992; Boudon 1986). Most important is the burgeoning research field of transition management (Rotmans et al. 2001; Brugge & Rotmans 2006; Geels 2002). We consider its insights and their relevance to adaptation crossroads in the discussion section.

2.2 Adaptation decision support

Decision support is the provision of scientific information to support governance decisions. This linking of science with user needs is a multifaceted problem with no simple solutions. There are three broad characteristics that information must have to be useful and for which an equal balance should be struck: salience, credibility and legitimacy (Cash et al. 2002; Cash et al. 2003). Salience means that the information is context-specific and relevant for the decision at hand. It implies the consideration of different temporal, spatial and administrative scales (Cash & Moser 2000). Credibility means that users perceive the information to be accurate, dependable and of high quality, while legitimacy means that the producers of information are seen to be politically unbiased and that they keep the users' interests in mind (Cash et al. 2003). Rather than just providing scientific outputs without consideration of their use (the "loading-dock" approach, Cash et al. 2006), decision support needs to tailor scientific information to the problems it will be applied to.

The continued interaction and trust between the providers of decision support and its users is important to long-term success. This involves 'boundary management' between science and policy through some type of organizational arrangement. A long-term effective strategy for decision support has three key features (Cash et al. 2003): it treats management of the science-policy boundary seriously, uses 'boundary objects' (such as models designed specifically to bring stakeholders together) and is accountable to actors on both sides of the science/practice boundary. Thus, in addition to saliency, legitimacy and credibility, the importance of providing avenues of negotiation and mediation is equally high. Desired outcomes often differ between different actors using the information provided (Cash et al. 2003), and the actors may also have different criteria for what constitutes credible information.

The existence of adaptation crossroads is relevant for decision support because it implies that both users and their information needs change in unpredictable ways. Since trust and a good relationship are particularly important for a well-working science-policy interface (Patt 2009; Patt et al. 2005; Carberry et al. 2002; Pretty 2003), the failure to prepare adequate decision support to deal with crossroads could also damage science-policy interactions in the longer term. How exactly adaptation crossroads will shape the decision support necessary to deal with them is too early to tell. It is necessary however to explore in broad terms what needs to

be taken into account in the design of decision support and flag some key questions, which we intend to do in this work.

3 Three case examples

Three cases illustrate the concept of adaptation crossroads. The first is historic, while the other two are current. For each case, we look at the decision situation before identification of a crossroads, at the possible crossroads, and then, depending on whether the crossroads has been identified, at the resulting changes to policy, and if it has not been, on what implications are likely.

3.1 Historic case: The U.S. 'Dust Bowl' in the 1930s

The 1930s Dust Bowl in the U.S. Southwest is a historic example of an adaptation crossroads (Worster 1979). During the westward expansion of farming, the native grasslands were turned into farmland, replacing drought-resistant vegetation with largely drought-intolerant crops. Growing mechanization greatly accelerated this process. The initial decision situation was primarily defined by small farmers as the main actors. These had moved into the Great Plains as settlers, driven by the fundamental idea of westward expansion into 'empty' lands since the 19th century. The idea that land not under cultivation is wasted was prevalent. The land management strategy was incomplete and often non-existent, in particular, there was little erosion control or measures to deal with drought (Worster 1979). The large number of small farms created a collective action problem, as the decision to implement control measures such as fallow strips would decrease a farm's production, while most of the negative effects of soil erosion would be shared by neighboring farms (Hansen & Libecap 2004). Government oversight and management of the small farmers was generally limited, though the issue of reaching them was recognized in various government agencies (Hansen & Libecap 2004).

3.1.1 Crossroads

Severe drought conditions throughout the 1930s exposed the unsustainable nature of the system. Abnormally high temperatures were caused by El Niño-Southern Oscillation conditions, and were likely amplified by the land degradation (Cook et al. 2009). The result was massive drought and then crop failure, which lead to widespread loss of topsoil through wind erosion, making further cultivation all but impossible in some areas. This led to a cascade of further effects: loss of jobs, economic decline and collapse, and outmigration of the destitute, primarily to the West Coast. The expectation was initially that the drought would be short, and that therefore no fundamental changes in management would be necessary (Hansen & Libecap 2004; Worster 1979). In hindsight one can therefore argue that the adaptation crossroads was, although anticipated by some, not generally prepared for.

3.1.2 Changes to the decision situation after the crossroads

Indications of the problem worsening, including dust storms carried to Washington D.C. and other coastal cities, led the federal government to realize the severity of the situation. The problem moved from a decision problem of individual farmers, and then local agencies, up to the federal scale. The magnitude of the problem lent weight to an increased focus on more holistic land use planning, and the realization that 'empty' land is not necessarily wasted. The implications of the crisis also went beyond agricultural planning. Dealing with migration from affected states into areas such as California required state and local governments far from the original problem to deal with its fallout (McLeman & Hunter 2010). Two successive Great Plains Committees were appointed to work on solutions. The Soil Conservation Service (founded as the Soil Erosion Service in 1933) showed farmers the benefits of conserving soils, starting from 1934, and after 1937 moved to 'soil conservation districts' to coordinate erosion control (Hansen & Libecap 2004).

It is easy to dismiss the Dust Bowl as an episode of the past where unfavorable climate conditions coincided with agricultural mismanagement. However, Rosenzweig and Hillel (1993) suggest that the Dust Bowl can be seen as a early analog of possible future climate

conditions in that area, and model projections suggest that a return of dust bowl-like drought in the Southwestern United States is imminent in a timeframe of years to decades (Seager et al. 2008). Furthermore, if climate change continues unabated, we can expect to see similar conditions in other world regions permanently (Solomon et al. 2009). The Dust Bowl demonstrates that management approaches can fail in catastrophic ways, resulting in dramatic changes over short periods of time.

Can the Dust Bowl be seen as an adaptation crossroads? The underlying drivers were both unsustainable agricultural practices as well as unsustainable economic expansion. The prolonged drought however, a climatic factor, is what exposed the unsustainability and triggered the system's collapse. Later droughts in the 50s and 70s did not result in another Dust Bowl (Hansen & Libecap 2004), which could suggest successful adaptation after changes brought about by the crossroads (although the economic depression of the 30s was a further factor making the effects of that drought so severe).

3.2 Water management in the Netherlands

In the Netherlands, a discussion of 'adaptation tipping points' has emerged in national policy (Kwadijk et al. 2010). The definition of adaptation tipping points there is points where the current management approach fails. The potential adaptation tipping points identified within that definition can be seen as a subset of a wider field of potential adaptation crossroads. In this case we do not aim to comprehensively describe these tipping points. Rather, we attempt to explore the changes to the institutional and decision-making setting that emerged as a response to the tipping points discussion through the implementation of the so-called Delta Programme. These changes may hold lessons for adaptation crossroads more generally.

3.2.1 Decision situation leading up to the identification of adaptation tipping points

The Dutch national government has acknowledged that the water infrastructure and management system were not prepared for the twenty-first century (Commissie Waterbeheer 21e Eeuw 2000; V&W 2001a). Near floods and costly urban storm water events in the 1990s, along with the first projections of climate change, underlined that raising dikes and driving out water would not bring about sustainable flood safety in the Netherlands. They suggested changing water management from a technical expert dominated sector focussing on technical measures and efficiency to a governance-oriented sector with the objective to enhance the resilience of the system by creating space for water. Three years after the flood threats a 'National Governance Agreement on Water' (V&W 2001b) was signed by provincial, water board and municipal authorities together with the national government. This national agreement was followed by a river restoration program, called 'Room for the River'.

New momentum for anticipating long-term climate change impacts came with the appointment of a committee – the second[3] Delta Committee – by the Dutch government in 2007. The Delta Committee was established as part of the government's Vision for Water (approved by Cabinet on 7 September 2007) with a broad mandate and long-term time horizon (2100-2200). The committee was asked to evaluate the potential effects of climate change and to propose measures to "climate-proof" the country; that is, to keep it safe from flooding, while preserving its status as an attractive place to invest in, work and live (Kabat et al. 2005; New Delta Committee 2008; Kabat et al. 2009). The committee concluded that the Dutch can continue to live in their flood-prone delta region. In this respect, no adaptation crossroads was projected within the 2200 time horizon. Yet the committee added that action is needed to improve flood protection, as the current flood protection system will fail to meet flood protection standards in the future, and in some places, even the current standards are not met. Thus, failing to meet flood protection standards was identified as an adaptation management tipping point. The government responded to the Delta Committee's recommendations in the National Water Plan (Ministerie van Verkeer en Waterstaat 2008), which calls for the design and implementation of the so-called Delta Programme. The Delta

[3] The first Delta Committee had been installed after a devastating flood of 1953, which killed about 2,000 people and had resulted in a spectacular reinforcement of the coastal protection system.

Programme augments the previous water management policy in exploring long-term strategic alternatives and making long-term financial reservations.

3.2.2 Identification of adaptation tipping points

With climate change and long-term water safety as new themes in water management, the Ministry of Transport and Water Management commissioned various background studies. In 2007 the concept of 'adaptation tipping points' was advanced for a policy study of long-term water safety. It proved successful to assess and communicate water related risks (Kwadijk et al. 2010). The Delta Programme took up the concept and identification of adaptation tipping points became explicitly recognized and increasingly central in the legitimisation of long-term planning. The main potential adaptation tipping points from the policy study that have been taken up in the Delta Programme are:

- In the IJsselmeer Lake, when sea water levels cross a certain level, gravity drainage will be practically impossible at the current IJsselmeer level.
- Freshwater supply in the midwest of the Netherlands (an area between the Rhine Estuary, the Amsterdam-Rijn canal and the Noordzee canal), being jeopardised by salt seawater intrusion due to rising sea levels and reduced river discharge in the summer. At present, freshwater availability depends on fresh water diversions from outside the region. Longer dry periods could increase the competition for fresh water, leaving the current management approach in trouble.
- Current safety strategies in the lower river reaches are now based on giving the river more room and a movable defence system (the Maeslantkering storm surge barrier). Extreme river discharges in the winter are expected to increase, while the sea level rises. After 2050, the current strategy to keep the lower reaches safe will probably no longer be effective.
- Regionally and locally, the social acceptance of increased water logging and damage as well as the willingness to bear the increasing social costs for technical solutions to existing infrastructure such as sewage treatment, may run into limits. This is recognized as potential adaptation management tipping points that need to be regionally assessed and anticipated.

3.2.3 The Dutch Delta Programme as an institutional response to potential adaptation crossroads

The Delta Programme could be seen as an early example of a response to the need for anticipating emerging adaptation crossroads. It is a new policy pathway that is implemented alongside the established policy stream of the National Water Plan. The new governance bodies created for the implementation are temporary, yet its members are civil servants drawn from existing government bodies. At the same time, the Delta Programme is supported legally by a Delta Act and organisationally by a newly appointed Delta commissioner. The position of Delta commissioner was specifically created for the Delta programme to report annually on the progress made towards the Delta Decisions. The guidelines for the implementation of the Delta programme follow a recent policy advice 'Faster and Better' (Sneller en Beter, Commissie Elverding 2008) to speed up the decision-making processes by exploring strategic alternatives and early selection of one development direction to be advanced in an implementation plan. This approach was considered appropriate to facilitate the strategic planning process in anticipation of adaptation tipping points. The approach diverts from the prevailing Dutch 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 very limited. Here the implementation diverts from the advice 'Faster and Better' that recommends early active involvement of these agents in exploratory regional development activities (Commissie Elverding 2008). Presently, the responsibility lies exclusively with

national government agents. A Ministerial steering group with representatives of six ministries, chaired by the Prime Minister was created in 2009 to head the implementation of the Delta programme. The program is implemented in a series of subprograms that focus on a particular long-term adaptation management tipping point and associated strategic decision that water managers will have to consider.

The subprograms are supported with guidelines and a general time schedule, offered by the Delta commissioner and his staff. The political responsibility for each subprogram lies with one or two ministries and its responsible minister or state secretary. The organisation of each subprogram is commissioned to a high level administrative agent in the responsible Ministry. Together these agents form the Director General Counsel that prepares the Ministerial Steering Group. The subprograms can design their own sub-bodies and responsibilities for the implementation. In practise, the program teams of the subprograms consist of civil servant from the local, regional and national government.

3.2.4 Implication for knowledge creation and decision support

In this section we describe the decision support tools created for the Delta Programme. It could thus serve as an example of the type of tools that actors perceive as appropriate for addressing adaptation crossroads. One of the main aims of the Delta programme for the coming years is the development of knowledge in support of decision-making.

The main mechanism proposed for facilitating knowledge creation and decision support is joint-fact-finding. At present this is mostly organised through consultation workshops and by the cooperation of government actors and experts in the subprogram team. The implementation process is structured in small steps, allowing for responding to new insights. Yet, the planning process from scoping to selection of alternatives foresees little feedback and possibilities to go back to scoping, for example, when new information becomes available. As part of their Plan of Action and in support of the Delta Decisions, the nine sub-programmes have established a knowledge agenda containing approximately 350 knowledge questions that cover a wide range of topics, from strategic to operational and from finding quick answers to setting up long-term research projects (Delta Commissioner 2010). Some subprograms have commissioned policy explorations ahead of the planning of the subprogram. The ministries involved continue to rely on the research institutions traditionally associated with each ministry.[4]

Various tools are created to support in particular the coherence of the strategic decisions to be taken in the Delta Programme. These include i) a set of common scenarios, ii) a set of evaluation criteria for appraising and comparing alternative strategies, and iii) a "Delta model" for the simulation and appraisal of strategic alternatives. More recently, as implementation unfolds, the need is felt to harmonise the activities of the subprograms and formalise procedures. This has resulted in a series of guidelines on the policy cycle towards the 'Delta decisions', the identification of (regional) adaptation tipping points, and the design of strategic policy alternatives. Under preparation are guidelines on addressing uncertainty in the decision process and the valuation of long-term costs and benefits of strategic alternatives. This includes the valuation and communication of the relative advantages of robustness and flexibility in design; key challenges that have also been identified in the other outputs of the MEDIATION Project (see MEDIATION Deliverable 4.1). It is too early to tell whether the approach selected in the Netherlands is appropriate for decision-making under approaching adaptation crossroads. Yet, the challenges it faces could serve as the basis for future research to address the emerging adaptation problems.

[4] For readers familiar with Dutch organisations: the Ministry of VenW relies on the institute Deltares for knowledge support, LNV on the institute Alterra, and VROM on the planning bureau PBL. For example, the instruction of the subprogram New Construction, which is coordinated by VROM, is the only instruction recognising PBL studies.

3.3 Tourism in the Alpine region

In the European Alps, economic pressures combine with fluctuations in annual snowfall in determining whether winter tourism is economically attractive and viable in a given community. Mountain areas are particularly vulnerable to climate change (Diaz et al. 2003; Schneider et al. 2007). Warming in mountain regions appears to mirror average warming in a given latitude, possibly even exceed it (Beniston 2003; Nogués-Bravo et al. 2007). This means that snowfall becomes less frequent, furthermore, there is a correlation between mean winter temperature and snow day anomalies (Marty 2008). Snow cover is also affected by local factors, therefore the extent of its reduction will differ across regions and resorts (Uhlmann et al. 2009).

Snow insecurity is not a new phenomenon; climate change impacts on mountain tourism have been on the research agenda since the 1980s (Dubois & Ceron 2006). However, climate change severely exacerbates the problem and carries it into areas where it was of little concern in the past. A body of work analyzing vulnerability and adaptation strategies has started to emerge (Scott & McBoyle 2007; OECD 2007). Moreover, other factors will drive change in tourism too, possibly to a greater extent than climate change (Hamilton et al. 2005). Snow security is a necessary but insufficient factor for economically viable winter tourism. For instance, the number of skiers has stagnated over recent years in Switzerland (Müller et al. 2007). Locals employed in tourism cannot adapt as flexibly as tourists that can simply choose the ski resorts with favorable snow conditions (Elsasser & Bürki 2002), therefore, the difficulty of adaptation is primarily on the tourism operators. Across the alps, about 90% of a total of 666 ski resorts are naturally snow-reliable today, but this would drop to about 60% with only 2°C mean global warming, and to 30% with 4°C (OECD 2007).

3.3.1 Current decision situation

In some mountain areas in Switzerland, tourism is responsible for more than 80% of GDP (Müller et al. 2007). Therefore, the primary focus is on keeping tourism afloat as a source of income. Although there is some thinking amongst some local stakeholders to diversify within tourism (Disch & Reppe 2007), diversifying away from tourism is not a major discussion point in many cases (Hill et al. 2010; OECD 2007). The focus in local stakeholder views from several studies appears to be on preserving the status quo with technical solutions, particularly artificial snowmaking (Hill et al. 2010; Steiger & Mayer 2008; Wolfsegger et al. 2008; OECD 2007), there is a general conviction that future (technical) adaptation will solve the issue (Scott & McBoyle 2007; OECD 2007). This is not surprising, as the primary group that is affected are operators of mountain railways, ski lifts and cableways, and these represent a highly technological approach to winter tourism. The hotel sector and other tourism operators are affected indirectly but have less possibilities to manage direct adaptation.

3.3.2 Decision support

Climate change has become a topic of discussion for winter tourism earlier than in other tourism areas because of the dependence on snow security (e.g. Bürki 2000). One study found that local stakeholders mistrust the available information on climate change and downplay the potential consequences, while oh the other hand they use climate change projections to vindicate their strategies (Elsasser & Bürki 2002). The scientific information available at the moment is not very location-specific across different alpine regions, but various research efforts are under way (e.g. funded by national bodies such as the Swiss Tourism Association STV[5], as well as various European projects like ClimAlpTour[6]). The existing literature on winter tourism and climate change has focused on only few adaptation options and therefore, more possibilities to adapt may exist and the effects may be less severe than first thought (Scott & McBoyle 2007). There appears to be no comprehensive planning approach to deal with climate impacts yet (OECD 2007; Scott & McBoyle 2007). Adaptation,

[5] http://www.swisstourfed.ch/index.cfm?parents_id=1668
[6] http://www.climalptour.eu/

in general, is individualistic and reactive (Scott & McBoyle 2007).

3.3.3 Adaptation crossroads

Changes in snowfall trends are not the only issue resulting from climate change: weather anomalies increase, permafrost melts, causing problems with infrastructure built on it, and glaciers disappear, resulting in the loss of ski slopes and decreased attractiveness of the landscape. This will put further economic pressure on mountain resorts (Bürki et al. 2003). Weather conditions appear to have a significant effect on downhill ski ticket sales (Shih et al. 2009). A survey of Swiss skiers also found that one-third of the sampled market would ski less or quit altogether under climate change conditions (Bürki 2000), although surveys in other countries found less dramatic effects (Scott & McBoyle 2007).

The adaptation crossroads that results from this is when physical and economical factors together lead to a point where operating ski tourist infrastructure is no longer economical in a given community. When this threshold is reached would depend very much on the individual situation of a given resort. After this point, however, alternatives to the previous approach to winter tourism are be needed. Artificial snow-making can forestall the crossroads for some time. There are however several studies that suggest caution in relying on artificial snow-making for the future, as it becomes difficult or even impossible if temperatures are not low enough, has high energy and water requirements, and is expensive (Hamilton et al. 2007; Scott et al. 2006; Vanham et al. 2009; Steiger & Mayer 2008). In some areas, particularly higher-lying resorts, it will be sufficient for the foreseeable future (Scott et al. 2006). Overall, snow-making may only prolong an inevitable adaptation crossroads, and is a maladaptation in the meantime through its contribution to climate change and environmental destruction (EEA 2009).

3.3.4 Changed decision situation in light of the adaptation crossroads

Some lower lying resorts have already reached a point where their ski infrastructure is uneconomical, and there seems thus in such areas a beginning of thinking beyond winter tourism. For instance, the 'Plan Tourisme Savoie 2007-2013' intends to diversify tourism into all four seasons and allocates 37 million EUR out of a total budget of 60 million EUR for that purpose (Savoie Conseil General 2007).

Given that crossroads will be reached at different points in time in different regions and different communities, there are several broad options with varying degrees of severity that can be considered in each case. At first, measures to adapt ski tourism incrementally will remain relevant for the foreseeable future in some resorts, and will allow some resorts to avoid the crossroads altogether. Resorts in the high Alps have the possibility to move operations higher up (Bark et al. 2010). Resorts that are likely to retain snow stability for several decades should probably focus on measures to preserve their winter tourism, at least initially. One point to further explore here are the implications of moving from lower-lying, isolated ski resorts, towards higher-lying areas where several resorts are linked into large skiing area. This would change the dynamics of decision-making towards a more regional level.

There are two ways forward after reaching an adaptation crossroads, if it cannot be avoided. First, a refocus on other touristic activities. Some ski infrastructure, like lifts, is also usable for summer tourism. Some might be dismantled, this must be planned, i.e., there must be a plan for what replaces it. An example in Germany shows that it is feasible for a smaller resort to completely dismantle all ski lift infrastructure and renaturalize ski slopes (Dietmann et al. 2004), moving to low-impact (summer) tourism and ski tours. Summer tourism is not without problems. Summer precipitation and run-off are projected to decrease though climate change, but a shift to summer tourism would mean higher water requirements in that time (Leipprand et al. 2008). Summer tourism brings much less income than winter tourism, even when tourist numbers are roughly equal (Müller et al. 2007). In some areas, tourism at the same scale may therefore simply no longer be viable. Wellness holidays could create value for summer

tourism (Müller et al. 2007). However, it is unclear to what extent tourists will be attracted by alternative offerings that do no involve downhill skiing (Hoy et al. 2010) and what their choices will be as the attractiveness of entire regions decreases (Scott & McBoyle 2007).

The second class of measures, which is much more drastic, would be a refocus on other economic activities. This is unlikely to be a major strategy for many areas in the foreseeable future. Nevertheless, diversifying the alpine economy would have important benefits for sustainable mountain communities, independent of climate change.

Of particular note is the issue of competition. Competition for tourists will intensify both within communities (e.g. as tourist numbers become too low to sustain the current number of hotels in a community), between communities, and possibly between entire ski regions. There is evidence that higher-altitude resorts are not yet affected while lower altitude resorts are losing customers (Teich, et al. 2007). Thus, a division into 'winners' and 'losers' is likely as climate change progresses (Elsasser & Messerli 2001; Scott & McBoyle 2007), in other words, there will be crossroads in some areas but not in others. If high-altitude resorts capture customers from lower resorts as these close, they could even expand their operations (Bürki et al. 2003). The ecological implications as well as the changed transport demands may necessitate rethinking tourist flows on a broader, regional scale. These issues will need to be better understood and managed.

3.3.5 Implications for decision support

There are several aspects to consider for decision support. First, the decision whether to continue adapting ski tourism or whether to shift to other activities needs, among other information, climate forecasts. This also includes better climate forecasting for seasonal decisions such as when and how to commence snowmaking, and better weather forecasts to optimize day tourism (the urban backyard phenomenon, where tourists from cities must be convinced to come to mountains even when there is no snow in their own backyards). The decision also needs consideration of a wider range of adaptation options within studies of adaptive capacity and future scenarios (Scott & McBoyle 2007). Another question surrounds the demand-side. How do tourists decide whether and where to ski? This may differ among regions and local skiing culture. Furthermore, not every ski region has the same business model, and a single resort is more vulnerable to tourist decisions than a company with operations across a larger area.

Anticipating the crossroads, as a basis for making decisions about which path to take, is a key open question. If moving away from winter tourism, entirely different types of information will be necessary, as well as many other changes.

A study of corporate adaptation behaviour amongst Swiss ski lift operators found that the most vulnerable companies do not engage in the most adaptation, the reasons for which are unclear (Hoffmann et al. 2009). This could indicate that these companies see a futility of adaptation in face of their vulnerability. In light of potential adaptation crossroads this could be a reasonable stance: they should then instead be supported through measures designed to move away from their current skiing business model. On the other hand, such companies might also perceive their adaptive capacity as lower than it objectively is (Grothmann & Patt 2005). More participatory work with local stakeholders will be needed to understand and manage the issues faced by them, and to positively make use of such findings (Loibl & Walz 2010).

4 Discussion

Here we intend to discuss in more detail our second question: what are the implications of the existence of adaptation crossroads?

Adaptation crossroads can not be seen as static in time and space. The decision situation shifts constantly and may be influenced by the anticipation of a crossroads. In the Dust Bowl case, some warning voices were trying to change management strategies before and throughout the 1930s, but did not succeed. If they had, the radical changes that took place may not have been

as extreme, and the transition would have been more gentle. In the Netherlands, discussion of crossroads already appears to be changing the decision situation. Indeed, in an ideal case, decision crossroads will not result in sudden or ill-managed transitions because far-sighted planning soothes the transition. This means that decision support should support decision-makers in identifying possible crossroads beforehand. In the alpine case, the focus appears predominantly on technological solutions for some actors, which may move them closer to an eventual crossroads without adequate preparation. The alpine case underscores the well-known importance of focusing on bottom up processes. Beyond supporting decision-makers at national or subnational scales, local communities, businesses, individuals are ultimately the ones that make or break successful adaptation.

As described above, well-working decision support should have three main features: saliency, credibility, and legitimacy. The cases suggest that in the climate change adaptation context and when adaptation crossroads are involved, i.e. when the future can be expected to develop quite differently from the past because of climate change, credibility is of particular importance. In the Netherlands case, established credibility of the science informing water policy meant that identified adaptation crossroads were taken up into the policy process. Therefore, policy makers might generate solutions to avoid them (it is too early to tell whether this will happen, and if it does, whether it is successful). In the alpine case, it appears that in the absence of a unified planning process, some local stakeholders have a certain amount of skepticism regarding predictions of severe climate change, choosing to stick to existing technological solutions in the expectation that they will remain possible. They may continue working in many cases, but in others they might instead build a false sense of security while an adaptation crossroads comes closer. Making plans that depart from current way of doing things requires particularly strong and credible information.

Both the Dust Bowl and the Alpine case illustrate the danger of maladaptation. In those cases, it seems like the danger would not just be that adaptation crossroads are not recognized early enough, but that unsustainable practices are even extended in a direction opposite to what the existence of crossroads ahead would suggest. This may work for a while, for instance if artificial snowmaking can stave off decisions about the future of a resort area. If the impact variable continues to move toward the threshold, however, this would just delay a necessary decision and possibly greatly increase its difficulty when it eventually has to be made.

Anticipating crossroads is what is ultimately necessary if the concept is to have an impact on planning. In order to aid doing so, we determine some key properties that appear important to differentiate them.

Second is the rigidness of the threshold. Other factors besides climate drive social and economic changes to the point of tipping. In our framing, climate is different from other factors because it defines the boundary conditions within which human activity takes place. This boundary is shifting rapidly now as humans change atmospheric conditions, but in the context and scale at which adaptation takes place, it can be seen as an exogenously given boundary. Economic, social and cultural conditions are endogenous to society, therefore, they can also shift as opinions, values and outlooks change. Thus, we can divide adaptation crossroads into two groups. First, where there is a hard ceiling, i.e., a point beyond which bio-physical limits to adaptation come into play (and overcoming resilience to change might be particularly important). Second, where there is an open sky, i.e., where the problem is primarily defined by social or economic preferences that could change, which suggests that the adaptation crossroads could be averted by social, technical and policy changes. This is where useful adaptation can take place. Because we have some idea about the future climate based on our greenhouse gas emitting activities, we can, if we chose, limit the emissions so that hard ceiling situations are avoided; this is a question of mitigation.

Table 1 gives an overview of this classification.

The first and most important is the type of change that the decision situation undergoes. This

is also the least well defined, because more case studies will be needed to determine the most frequent and likely types of changes. From our cases, several types of change suggest themselves: a shift from one actor to many actors, a shift from a local scale to a subnational or national scale, a shift from being unmanaged or leniently managed to being managed more strictly, i.e. from being left to personal judgment of individual actors to being under the authority of a government agency. Many of these changes imply that the user group changes. This leads to a further important implication for decision support: the decision support system itself has to remain effective as adaptation crossroads are reached and passed. That will require moving to a fluid understanding of user groups and how they change, anticipating those changes and preparing for them ahead of a crossroads.

Second is the rigidness of the threshold. Other factors besides climate drive social and economic changes to the point of tipping. In our framing, climate is different from other factors because it defines the boundary conditions within which human activity takes place. This boundary is shifting rapidly now as humans change atmospheric conditions, but in the context and scale at which adaptation takes place, it can be seen as an exogenously given boundary. Economic, social and cultural conditions are endogenous to society, therefore, they can also shift as opinions, values and outlooks change. Thus, we can divide adaptation crossroads into two groups. First, where there is a hard ceiling, i.e., a point beyond which bio-physical limits to adaptation come into play (and overcoming resilience to change might be particularly important). Second, where there is an open sky, i.e., where the problem is primarily defined by social or economic preferences that could change, which suggests that the adaptation crossroads could be averted by social, technical and policy changes. This is where useful adaptation can take place. Because we have some idea about the future climate based on our greenhouse gas emitting activities, we can, if we chose, limit the emissions so that hard ceiling situations are avoided; this is a question of mitigation[7].

Table 1: Properties for a typology of adaptation crossroads

Property	**Description**
Type of decision change	Shift between scales, shift from one to many actors, changes in institutional setting, changes in range of impacts the decision has, expansion of decision problem from one economic sector to multiple sectors
Threshold rigidness	Is the adaptation crossroads primarily defined by bio-physical constraints (ceiling) or is it defined by social or economic boundaries that might shift (sky)?
Extent of advance recognition	Is the adaptation crossroads recognized before it is passed, or only afterwards? If it is detected beforehand, is sufficient action taken?
Scale of concern	What is seen as an issue of great importance to some people (e.g., the persistence of skiing in a particular resort) may seem irrelevant to others.

Third, recognizing a potential adaptation crossroads in advance should be the goal of scientific decision support, taking action to circumvent it or manage the transition should be the goal of policy. Science may recognize a crossroads, but it may not be widely recognized amongst stakeholders, leading to unsustainable behavior. If a crossroads is widely recognized,

[7] On the other hand, future technological advancements could mean that what are hard ceilings now can be scaled at some point in the future.

policy can start to generate strategic alternatives and which policy paradigm to follow in dealing with the crossroads. Only then can a shift away from incremental adaptation take place.

Fourth, the scale of concern could also interact with advance recognition. Some adaptation crossroads will be of national or even international concern, others, of local concern only. For instance, the coastal defense of major metropolitan areas is of national concern, while the economic woes of a mountain resort may be only regional. Bottom-up knowledge elicitation is needed particularly where top-down governance is prevalent, in order to help identify crossroads only relevant to a locally bounded group of stakeholders. This property may be more relevant in areas not discussed in our cases, for instance, for vulnerable agricultural production systems tied to a specific and often small geographic region such as coffee or wine. While growing wine or coffee may be of paramount importance to a specific regional economy, in the global market context it is of little importance where exactly wine or coffee is produced.

More concretely, how can decision-support systems identify specific and quantifiable adaptation crossroads? For some areas, future policy questions will revolve around defining limits until which an existing management strategy is kept up. There are a economic methods which could assist in defining limits after which costs become too high to be viable. The application of cost-effectiveness analysis (CEA) could be one way to do this (see MEDIATION Deliverable 3.2 for a detailed treatment on this topic). Deltares in the Netherlands has developed a guide to identifying crossroads/tipping points and adaptation pathways (Te Linde & Jeuken 2011), which details the approach presented by Kwadijk et al. (2010). It has two overarching components: first, performing an analysis of how much change the current management system can deal with, and second, using plausible climate scenarios to determine over range of time the system might reach its limits. Kwadijk et al. (2010) use a mixture of policy analysis, interviews and climate scenarios to predict when the current management system reaches limits. This approach is very useful in areas where knowledge of future impacts is more certain, as is the case in sea level rise.

In other areas, building quantitative scenarios may be more difficult, and a more qualitative exploration of possible crossroads will be necessary. The question would then be more focussed on what types of major changes could be seen and where crossroads could lead. Normative scenarios to explore potential futures could be equally valuable in many cases. This is also where transition management can contribute much. Transition management is a proactive and anticipatory strategy that focuses on managing transitions in a gradual way, focussing on bottom-up innovation and linking to on-going dynamics rather than forcing change (Rotmans et al. 2001). In particular the focus on a gradual transition is what should be aimed for in dealing with adaptation crossroads: slowly overcoming resilience to change in existing structures, without causing friction in the form of social resistance (Rotmans et al. 2001).

Insight from transition management highlights that keeping many options open is one key point, and ensuring a multi-scale and multi-actor approach is another. Long-term thinking (at least 25 years ahead) has become a commonplace recommendation in climate policy, and it is also underscored by transition management. The approach makes distinctions between the pre-development, take-off, acceleration and stabilization phases of a major transition. It also underscores the role of government in transition management by stimulating experiments and stoking discussions of what path society should take, particularly in the pre-development phase and to a lesser extent in the take-off phase. For this, insights from socio-technological transitions (Geels 2002) could, if adaptation innovations are seen as similar to wider technological innovations, be useful in supporting innovative approaches to adaptation problems in specific domains, to feed into a wider policy of transition management. The participatory process that results is not focussed on a static goal or blueprint, it is a goal-seeking process where goals and visions are constantly shifting (Rotmans et al. 2001).

Finally, and as an outlook for further work, we might differentiate two policy paradigms to

deal with adaptation crossroads (in addition to a third possibility of passively waiting for it): proactive avoidance through policy transformation, and building resilience. Both imply a fundamental change of the existing management approach, but they do so in a different way. The first paradigm means that an existing policy, recognized as insufficient, is replaced by another one. Catastrophic events can be seen as drivers of policy change, and climate change could be seen as a particular such catastrophe with the difference that it is the expectation of catastrophe, rather than the reaction to one, that drives change. A case study on floods in England (Johnson et al. 2005) showed that although disastrous floods served as catalysts of policy changes, they did not create entirely new ideas, rather, the possibly radical changes implemented after a disastrous flood were determined by the thinking that has gone on before the event, and the event itself merely opens a window of opportunity for these shelved ideas. This is an indication of the importance of building thinking in the right direction before an adaptation crossroads occurs. Path dependency makes this more difficult, which we note in all three cases. Our cases, if we span a continuum ranging from a policy transformation to a resilience approach, presently appear to lean towards policy transformation.

The second paradigm is resilience. Resilience is different because the focus is not on anticipating a certain change and building a policy to respond to it. Rather, the aim is to build ways to operate under fundamental uncertainty. Adaptive management could be one approach to achieve this resilience, and indeed was a part of the adaptation discussion from early on (Smit & Skinner 2002). In terms of recommending learning and evaluation, transition management and adaptive management are on a similar track. It relies to a big extent on learning from past events. This, however, presents difficulties if the future holds surprises, therefore, it may not be most suitable for climate change adaptation (Dessai & van der Sluijs 2007). Despite that weakness, in the Dutch case the fragmented implementation of the Delta programme might be turned into an advantage by recognizing them as a set of experiments, from which actors can learn through an adaptive management approach. In that sense, parts of the developments in the Dutch case could be seen as a move towards resilience.

The fact that the future can hold surprises and learning from past events is not always sufficient to deal with those surprises is important and will become more important with bigger climate changes yet to come, so learning has to acquire a more forward-looking dimension here. Supporting the process of building resilience is a key challenge for decision support. The Dutch case shows that the task of guiding thinking into new areas (the pre-development phase in transition management terms) is challenging at first: coming up with strategic alternatives to existing paradigms is difficult for stakeholders immersed in the existing approach. Moving further to build policy around not only dealing with unexpected events but even thriving under such conditions will be even more difficult and remains a question for future work.

5 Conclusion

In this paper, we define adaptation crossroads as thresholds beyond which an adaptation decision situation changes qualitatively from one type to another. Given that scientific information is a key component of adaptation decision-making, we explore the considerations for providing scientific decision support that result from the existence of crossroads. Using three cases, we look for commonalities and differences between different situations of adaptation crossroads.

We find adaptation crossroads in the past and present. They are being recognized, and a beginning of planning for them has started in the Netherlands. The importance of recognizing them beforehand goes hand in hand with the importance of legitimacy for useful and sustainable decision support. If it does not aid in recognition, decision support's legitimacy will be compromised. Three main implications for decision support emerge. First, decision support should help stakeholders anticipate adaptation crossroads, and by doing so, help avoid their negative effects. Second, it should allow stakeholders to become resilient to crossing such crossroads. Both of these points aim at the management strategy that the decision support system is meant to support. Both are also more easily said than done, as the Dutch

case shows: generating strategic alternatives is challenging for policymakers at first, but thinking into that direction needs to start earlier rather than later. Third and finally, the decision support system itself has to be designed to continue being effective in face of adaptation crossroads. This means dealing with the fact that the stakeholders, the types of institutions involved in the policy process, and the management problems themselves might change dramatically, while continuing to provide credible, salient and legitimate information.

The adaptation crossroads concepts could be particularly relevant outside of Europe, where vulnerability and impacts are more severe. Here there will be implications for the design of international development cooperation, but there may also be implications for the functioning of mechanisms such as the UNFCCC Adaptation Fund. Further work is needed and there are many areas where adaptation crossroads could be of importance, for instance with the spread of infectious diseases or with water-cooled electricity production if water becomes scarce. Sea level rise in small island nations and heavily populated megadeltas, and droughts in regions of Africa or the Amazon will likely bring about adaptation crossroads at entirely different magnitudes than the ones examined here. Real adaptation may often be defined by retreat and economic losses, rather than by incremental adjustments to cope with a new situation. Adaptation crossroads could be seen as the crucial issue in climate change adaptation, as they are instances where climate change results in challenges that are truly new and different. Many of them will have negative consequences, but at the same time, some of them might also be opportunities for beneficial change.

This paper is just a beginning and more work is needed to identify crossroads across different sectors and geographical regions. Questions remain about how to identify them, what factors cause them, and how to develop possible responses. In any case, taking crossroads from a purely speculative realm into serious policy planning is a necessity to ensure adequate preparation for them. There is an existing body of work in the areas of transition management, social theory as well as in ecology and resilience thinking. This knowledge will be useful in further developing insights and tools to understand and deal with adaptation crossroads. Transition management in particular gives insights that will be valuable to navigate adaptation crossroads. More work will be needed to apply these insights to climate change adaptation, and the path towards the crossroads is still a rocky one.

6 References

Adger, W.N. et al., 2007. Assessment of adaptation practices, options, constraints and capacity. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press, pp. 717-743.

Adger, W.N. et al., 2009. Are there social limits to adaptation to climate change? *Climatic Change*, 93(3-4), p.335-354.

Bürki, R., Elsasser, H. & Abegg, B., 2003. Climate change and winter sports: environmental and economic threats. In *5th World Conference on Sport and the Environment,(IOC/UNEP), Turin*.

Bürki, R., 2000. *Klimaänderung und Anpassungsprozesse im Tourismus - dargestellt am Beispiel des Wintertourismus*. PhD Thesis. University of Zürich.

Bark, R.H., Colby, B.G. & Dominguez, F., 2010. Snow days? Snowmaking adaptation and the future of low latitude, high elevation skiing in Arizona, USA. *Climatic Change*, 102(3), p.467-491.

Baumgartner, F.R. & Jones, B.D., 1993. *Agendas and instability in American politics*, University of Chicago Press.

Beniston, M., 2003. Climatic change in mountain regions: A review of possible impacts. *Climatic Change*, 59(1-2), p.5-31.

Biesbroek, G.R. et al., 2010. Europe adapts to climate change: Comparing National Adaptation Strategies. *Global Environmental Change*, 20(3), p.440-450.

Boudon, R., 1986. *Theories of Social Change: A Critical Appraisal*, University of California Press.

Brugge, R. van der & Rotmans, J., 2006. Towards transition management of European water resources. *Water Resources Management*, 21(1), p.249-267.

Brugnach, M. et al., 2011. More is not always better: Coping with ambiguity in natural resources management. *Journal of Environmental Management*, 92(1), p.78-84.

Carberry, P.S. et al., 2002. The FARMSCAPE approach to decision support: farmers', advisers', researchers' monitoring, simulation, communication and performance evaluation. *Agricultural Systems*, 74(1), p.141-177.

Cash, D.W., Borck, J.C. & Patt, A.G., 2006. Countering the loading-dock approach to linking science and decision making: Comparative analysis of El Niño/Southern Oscillation (ENSO) forecasting systems. *Science, Technology & Human Values*, 31(4), p.465.

Cash, D.W. et al., 2003. Knowledge systems for sustainable development. *Proceedings of the National Academy of Sciences of the United States of America*, 100(14), p.8086-8091.

Cash, D.W. & Moser, S.C., 2000. Linking global and local scales: designing dynamic assessment and management processes. *Global Environmental Change*, 10(2), p.109-120.

Cash, D. et al., 2002. *Salience, Credibility, Legitimacy and Boundaries: Linking Research, Assessment and Decision Making*, Available at: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=372280 [Accessed December 22, 2010].

Climate Analytics, 2010. Climate Analytics Web Page. Available at: http://www.climateanalytics.org/ [Accessed November 24, 2010].

Commissie Elverding, 2008. Sneller en Beter.

Commissie Waterbeheer 21e Eeuw, 2000. Waterbeleid voor de 21e eeuw - Advies van de Commissie Waterbeheer 21e eeuw.

Cook, B.I., Miller, R.L. & Seager, R., 2009. Amplification of the north american "Dust Bowl" drought through human-induced land degradation. *Proceedings of the National Academy of Sciences of the United States of America*, 106(13), p.4997-5001.

Deelstra, Y. et al., 2009. Veerman en Elverding: vernieuwing in waterbeleid en uitvoering. *H2O : tijdschrift voor watervoorziening en afvalwaterbehandeling*, 42(20), p.22-23.

Delta Commissioner, 2010. The 2011 Delta Programme Working on the delta; Investing in a safe and attractive Netherlands, now and in the future Ministry of Transport Public Works and Water Management, eds.

Dessai, S. & van der Sluijs, J.P., 2007. *Uncertainty and climate change adaptation: a scoping study*, Utrecht: Copernicus Institute.

Diaz, H.F., Grosjean, M. & Graumlich, L., 2003. Climate variability and change in high elevation regions: Past, present and future. *Climatic Change*, 59(1-2), p.1-4.

Dietmann, T., Polzer, E. & Spandau, L., 2004. Renaturierung des Skigebiets Gschwender Horn – eine Bilanz. *Jahrbuch des Vereins zum Schutz der Bergwelt (München)*, 68/69, p.235 – 248.

Disch, D. & Reppe, S., 2007. *Klimawandel in den Alpen. Fakten - Folgen - Anpassung*, Berlin: Bundesministerium für Umwelt, Naturschutz und Reaktorensicherheit.

Dovers, S.R. & Handmer, J.W., 1992. Uncertainty, sustainability and change. *Global Environmental Change*, 2(4), p.262-276.

Dubois, G. & Ceron, J.-P., 2006. Tourism and climate change: Proposals for a research agenda. *Journal of Sustainable Tourism*, 14(4), p.399-415.

EEA, 2009. Regional climate change and adaptation.

Eldredge, N. & Gould, S.J., 1972. Punctuated equilibria: an alternative to phyletic gradualism. *Models in paleobiology*, 82, p.115.

Elsasser, H. & Bürki, R., 2002. Climate change as a threat to tourism in the Alps. *Climate Research*, 20(3), p.253-257.

Elsasser, H. & Messerli, P., 2001. The vulnerability of the snow industry in the Swiss Alps. *Mountain Research and Development*, 21(4), p.335–339.

Folke, C., 2006. Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change*, 16(3), p.253-267.

Geels, F.W., 2002. Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, 31(8-9), p.1257-1274.

Grothmann, T. & Patt, A., 2005. Adaptive capacity and human cognition: The process of individual adaptation to climate change. *Global Environmental Change Part A*, 15(3), p.199-213.

Hamilton, J.M., Maddison, D.J. & Tol, R.S.J., 2005. Climate change and international tourism: A simulation study. *Global Environmental Change*, 15(3), p.253-266.

Hamilton, L.C., Brown, C. & Keim, B.D., 2007. Ski areas, weather and climate: Time series models for New England case studies. *International Journal of Climatology*, 27(15), p.2113-2124.

Hansen, J. et al., 2008. Target Atmospheric CO2: Where Should Humanity Aim? *The Open Atmospheric Science Journal*, 2(1), p.217-231. Available at: [Accessed September 8, 2010].

Hansen, Z.K. & Libecap, G.D., 2004. Small farms, externalities, and the dust bowl of the 1930s. *Journal of Political Economy*, 112(3), p.665-694.

Hill, M., Wallner, A. & Furtado, J., 2010. Reducing vulnerability to climate change in the Swiss Alps: A study of adaptive planning. *Climate Policy*, 10(1), p.70-86.

Hoffmann, V.H. et al., 2009. Determinants of corporate adaptation to climate change in winter tourism: An econometric analysis. *Global Environmental Change*, 19(2), p.256-264.

Howden, S.M. et al., 2007. Adapting agriculture to climate change. *Proceedings of the National Academy of Sciences*, 104(50), p.19691 -19696.

Hoy, A., Hänsel, S. & Matschullat, J., 2010. How can winter tourism adapt to climate change in Saxony's mountains? *Regional Environmental Change*. Available at: http://www.springerlink.com/content/7h7gl3681237354n/ [Accessed December 3, 2010].

Johnson, C.L., Tunstall, S.M. & Penning-Rowsell, E.C., 2005. Floods as Catalysts for Policy Change: Historical Lessons from England and Wales. *International Journal of Water Resources Development*, 21(4), p.561-575.

Kabat, P. et al., 2009. Dutch coasts in transition. *Nature Geoscience*, 2(7), p.450-452.

Kabat, P. et al., 2005. Climate Proofing The Netherlands. *Nature*, 438, p.283-284.

Kriegler, E. et al., 2009. Imprecise probability assessment of tipping points in the climate system. *Proceedings of the National Academy of Sciences of the United States of America*, 106(13), p.5041-5046.

Kwadijk, J.C.J. et al., 2010. Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. *Wiley Interdisciplinary Reviews: Climate Change*, 1(5), p.729-740.

Leipprand, A. et al., 2008. *Impacts of climate change on water resources - adaption strategies for Europe*, Dessau-Roßlau: Federal Environment Agency (Umweltbundesamt).

Lemos, M.C. & Rood, R.B., 2010. Climate projections and their impact on policy and practice. *Wiley Interdisciplinary Reviews: Climate Change*, 1(5), p.670-682.

Lempert, R. et al., 2004. Characterizing Climate-Change Uncertainties for Decision-Makers. An Editorial Essay. *Climatic Change*, 65(1/2), p.1-9.

Lenton, T.M. et al., 2008. Tipping elements in the Earth's climate system. *Proceedings of the National Academy of Sciences of the United States of America*, 105(6), p.1786-1793.

Loibl, W. & Walz, A., 2010. Generic regional development strategies from local stakeholders' scenarios - an alpine village experience. *Ecology and Society*, 15(3).

Marty, C., 2008. Regime shift of snow days in Switzerland. *Geophysical Research Letters*, 35(12).

McLeman, R.A. & Hunter, L.M., 2010. Migration in the context of vulnerability and adaptation to climate change: insights from analogues. *Wiley Interdisciplinary Reviews: Climate Change*, 1(3), p.450-461.

Meinshausen, M. et al., 2009. Greenhouse-gas emission targets for limiting global warming to 2°C. *Nature*, 458(7242), p.1158-1162.

Ministerie van Verkeer en Waterstaat, 2008. Ontwerp Nationaal Waterplan.

Müller, H., Weber, F. & Thalmann, E., 2007. *Klimaänderung und die Schweiz 2050: Tourismus*, Bern: OcCC. Available at: http://www.occc.ch/products/ch2050/ch2050-bericht_d.html [Accessed December 2, 2010].

New Delta Committee, 2008. Working together with water, A living land builds for its future - Findings of the Deltacommissie 2008.

Nisbet, R.A., 1992. *Social Change and History: Aspects of the Western Theory of Development*, Oxford University Press.

Nogués-Bravo, D. et al., 2007. Exposure of global mountain systems to climate warming during the 21st Century. *Global Environmental Change*, 17(3-4), p.420-428.

OECD, 2007. *Climate change in the European Alps: adapting winter tourism and natural hazards management*, OECD Publishing.

Parry, M., Lowe, J. & Hanson, C., 2009. Overshoot, adapt and recover. *Nature*, 458(7242), p.1102-1103.

Patt, A., 2009. Communicating uncertainty to policy makers. In P. Bayeve, J. Mysiak, & M. Laba, eds. *Uncertainties in Environmental Modelling and Consequences for Policy Making*. Springer, p. 231–251.

Patt, A., Suarez, P. & Gwata, C., 2005. Effects of seasonal climate forecasts and participatory workshops among subsistence farmers in Zimbabwe. *Proceedings of the National Academy of Sciences of the United States of America*, 102(35), p.12623.

Pfenninger, S. et al., 2011. *Report on perceived policy needs and decision contexts*, MEDIATION Project Deliverable Report.

Pretty, J., 2003. Social Capital and the Collective Management of Resources. *Science*, 302(5652), p.1912 -1914.

Rockstrom, J. et al., 2009. A safe operating space for humanity. *Nature*, 461(7263), p.472-475.

Rosenzweig, C. & Hillel, D., 1993. The Dust Bowl of the 1930s: Analog of Greenhouse Effect in the Great Plains? *Journal of Environmental Quality*, 22(1), p.9-22.

Rotmans, J., Kemp, R. & Asselt, M. van, 2001. More evolution than revolution: transition management in public policy. *Foresight*, 3(1), p.15-31.

Savoie Conseil General, 2007. Plan Tourisme Savoie 2007-2013. Available at: http://www.cg73.fr/index.php?id=769 [Accessed 2011].

Schneider, S.H. et al., 2007. Assessing key vulnerabilities and the risk from climate change. In *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press, p. 779–810.

Scott, D. & McBoyle, G., 2007. Climate change adaptation in the ski industry. *Mitigation and Adaptation Strategies for Global Change*, 12(8), p.1411-1431.

Scott, D. et al., 2006. Climate change and the sustainability of ski-based tourism in eastern North America: A reassessment. *Journal of Sustainable Tourism*, 14(4), p.376-398.

Seager, R. et al., 2008. Would advance knowledge of 1930s SSTs have allowed prediction of the dust bowl drought? *Journal of Climate*, 21(13), p.3261-3281.

Shih, C., Nicholls, S. & Holecek, D.F., 2009. Impact of weather on downhill ski lift ticket sales. *Journal of Travel Research*, 47(3), p.359-372.

Smit, B. & Skinner, M.W., 2002. Adaptation options in agriculture to climate change: a typology. *Mitigation and Adaptation Strategies for Global Change*, 7(1), p.85-114.

Smith, M.S. et al., 2011. Rethinking adaptation for a 4°C world. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 369(1934), p.196 -216.

Solomon, S. et al., 2009. Irreversible climate change due to carbon dioxide emissions. *Proceedings of the National Academy of Sciences*, 106(6), p.1704-1709.

Steiger, R. & Mayer, M., 2008. Snowmaking and climate change: Future options for snow production in tyrolean ski resorts. *Mountain Research and Development*, 28(3-4), p.292-298.

Te Linde, A. & Jeuken, A., 2011. Werken met knikpunten en adaptatiepaden: Handreiking.

Teich,, M. et al., 2007. *Klimawandel und Wintertourismus: Ökonomische und ökologische Auswirkungen von technischer Beschneiung*, Birmensdorf, Switzerland: Eidg. Institut für Schnee- und Lawinenforschung SLF.

Uhlmann, B., Goyette, S. & Beniston, M., 2009. Sensitivity analysis of snow patterns in Swiss ski resorts to shifts in temperature, precipitation and humidity under conditions of climate change. *International Journal of Climatology*, 29(8), p.1048-1055.

V&W, 2001a. Anders Omgaan met Water – Waterbeleid in de 21ste eeuw.

V&W, 2001b. Startovereenkomst Waterbeleid 21e eeuw.

Vanham, D., Fleischhacker, E. & Rauch, W., 2009. Impact of snowmaking on alpine water resources management under present and climate change conditions. *Water Science and Technology*, 59(9), p.1793-1801.

Walker, B. & Meyers, J.A., 2004. Thresholds in ecological and socialecological systems: a developing database. *Ecology and Society*, 9(2), p.3.

Warren, R., 2011. The role of interactions in a world implementing adaptation and mitigation solutions to climate change. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, 369(1934), p.217 -241.

Wilby, R.L. & Dessai, S., 2010. Robust adaptation to climate change. *Weather*, 65(7), p.180-185.

Wolfsegger, C., Gössling, S. & Scott, D., 2008. Climate Change Risk Appraisal in the Austrian Ski Industry. *Tourism Review International*, 12(1), p.13-23.

Worster, D., 1979. *Dust Bowl: The Southern Plains in the 1930s*, New York: Oxford University Press.