Climate change impact assessment and adaptation under uncertainty

Arjan Wardekker

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Climate change impact assessment and adaptation under uncertainty

Effectbeoordeling en aanpassing aan klimaatverandering onder onzekerheid
(met een samenvatting in het Nederlands)

Proefschrift

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Contents

Chapter 1.

Introduction

1.1. Climate change, impacts, and adaptation

Climate affects societies in many ways, and climate variability and change are important factors for societal development. Over the past century (1906-2005), global average surface temperatures have increased by 0.74 ± 0.18 °C (IPCC, 2007a). Based on observations of global air and ocean temperatures and changes in (among others) snow/ice extent and sea level, the Intergovernmental Panel on Climate Change (IPCC) concluded that it is 'unequivocal' that the climate system has warmed (IPCC, 2007a). Most of the warming since the middle of the 20th century is *very likely* (subjective probability of >90%) to be due to the human-induced increase of atmospheric greenhouse gas concentrations (IPCC, 2007a). Various impacts on physical and biological systems have been observed (IPCC, 2007b). Changes can however differ strongly at the regional level. For example, the observed Western European temperature trend over the past decades is much larger than the global average. Regional climate effects (changes in atmospheric circulation) and other regional environmental changes (lower aerosol concentrations) are believed to have played a role in this difference (e.g. PBL, 2009a).

Temperature projections for the end of the 21st century range from 1.1 to 6.4 °C[1], compared to end-20th century, based on the 'Special Report on Emission Scenarios' (SRES) scenarios for greenhouse gas emissions (IPCC, 2000, 2007a). These changes in the global average temperature have a wide variety of effects on global, regional and local levels, such as: changes (average and extremes) in temperature, sea levels, precipitation and river runoff, drought, wind patterns, food production, ecosystem health, species distributions and phenology, and human health (IPCC, 2007b). See Figure 1.1 for an overview. The impacts of these will differ per region and sometimes per season. In many cases, the impacts will be detrimental, although some regions might welcome some of the changes, provided they remain relatively small; e.g. in cold-limited regions limited warming could be useful for agriculture or access to mineral reserves. The impacts are, however, associated with large uncertainties. These are present in the context of the impact assessment (e.g. in the scenarios and climate data and projections used), and in each step of the assessment itself. They add up along the way, resulting in an 'uncertainty explosion' or 'cascade of uncertainty' (Schneider, 1983; Henderson-Sellers, 1993; Giorgi, 2005; Dessai and Van der Sluijs, 2007). See Figure 1.2. Wide-ranging socio-economic scenarios (e.g. SRES, but other, wider scenarios exist as well) lead to even wider ranging temperature projections. Global average changes affect local physical, biological, and social systems through complex 'cause-effect webs'; sometimes positively and negatively simultaneously. And, as

[1] Using the *likely* (>66% likelihood) ranges for each scenario; range of *best guess* estimates is 1.8-4.0 °C.

noted above, other (global, regional, or local) factors and trends can also modify the impacts. Coping with climate change remains a daunting challenge.

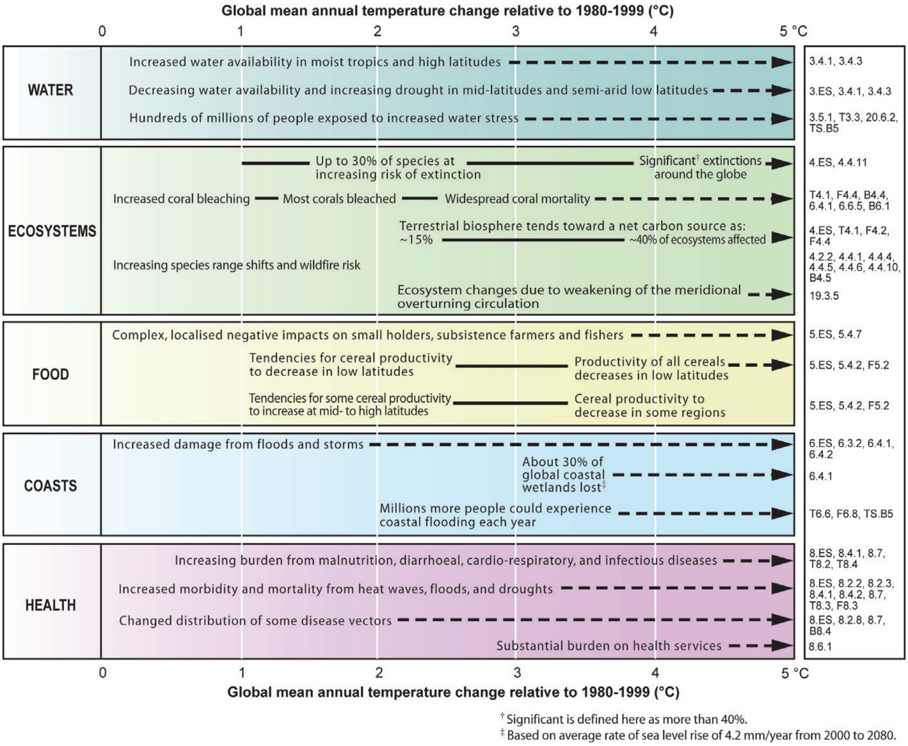

Figure 1.1. Overview of climate change impacts according to the IPCC AR4 (IPCC, 2007b) (numbers in the right-hand sidebar refer to the corresponding chapters in the AR4).

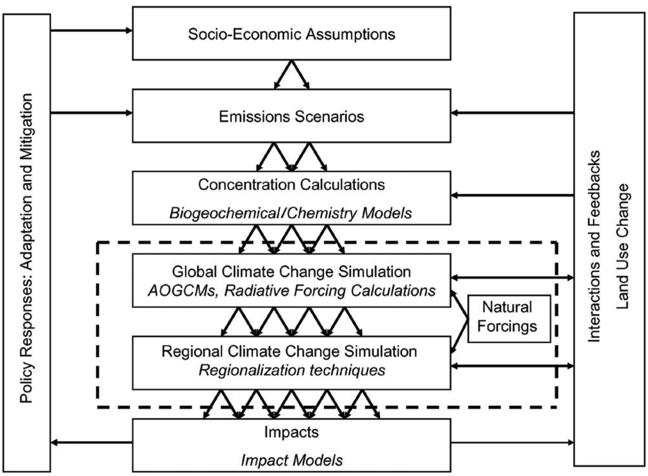

Figure 1.2. Cascade of uncertainties in climate change impact assessment (Giorgi, 2005).

Two main responses have emerged in recent decades to deal with climate change: mitigation and adaptation. Mitigation, limiting climate change e.g. by reducing greenhouse gas emissions, has understandably received much of the policy attention. Adaptation, defined as "*the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*" (IPCC, 2007b), is however also unavoidable. Even when taking an optimistic view on the successfulness and timeliness of emission reductions, some degree of climate change is inevitable (e.g. Smith et al., 2000; Dessai and Van der Sluijs, 2007; IPCC, 2007b); sizeable future emissions will likely remain and, due to the thermal inertia of the oceans[2], past emissions have not yet reached their full climate impact. Adaptation can also result in benefits regarding vulnerability to present-day climate and regarding economic competitiveness and attractiveness (see also Chapter 3). In fact, Runhaar et al. (submitted) assess that climate adaptation is often mainly an *additional* argument for measures taken in Dutch municipalities. Similarly, IPCC (2007b) points out that adaptation measures are seldom taken in response to climate change alone and are often embedded in broader sectoral initiatives.

The climate adaptation literature is rich in frameworks and concepts that relate to adaptation approaches and adaptation-related system characteristics; often with many overlapping and/or contesting definitions. Smit et al. (1999; 2000) indicate several dimensions that distinguish different climate adaptation approaches: purposefulness (planned versus autonomous adaptation[3]), timing (anticipatory versus reactive adaptation), temporal scope (short-term versus long-term), spatial and/or institutional extent (localized versus widespread), form (technological, behavioural, financial, institutional, informational), and function/effects (retreat, accommodate, protect; prevent, tolerate, spread, change, restore). Spatial and institutional extent may also relate to the issue of problem ownership; i.e. who is responsible for taking specific climate adaptation measures: national governments, municipalities, companies, or citizens? Walker et al. (2010) also address the question of whether policies themselves can be adapted. Given the large uncertainties in issues such as climate change, adaptive policies are called for. In climate adaptation thinking in the Netherlands, a distinction is made between measures aimed at increasing resistance, resilience, or adaptive capacity (e.g. Jeuken et al., 2008). The same distinction of resistance-resilience is also apparent in for instance Roggema (2008): resist versus coevolve with (climate) change, and in Bijlsma et al. (1996): protect, accommodate, or retreat. Considering the above, there are many different ways one could go about adapting society to climate change.

[2] Large volumes of water, such as the oceans, take a long time to warm or cool. Therefore, the effects (on e.g. temperature, sea level) of changes in atmospheric greenhouse gas concentrations take long to fully evolve. This implies that, even if greenhouse gas concentrations would be kept at current levels, additional warming would still be expected (e.g. Meehl et al., 2005; Hare and Meinhausen, 2006).

[3] Some interaction can occur; e.g. planned/anticipatory measures could be designed to enhance autonomous/reactive responses in the future.

1.2. Uncertainty

Decision-makers aiming to design adaptation measures face uncertainty regarding both the future climate and the 'best' adaptation approach. Uncertainty, from a decision-making point-of-view, can be described as "the gap between available knowledge and the knowledge policymakers would need in order to make the best policy choice" (Walker et al., 2010). Refsgaard et al. (2007) and Klauer and Brown (2004) define it as follows: "a person is uncertain if s/he lacks confidence about the specific outcomes of an event. Reasons for this lack of confidence might include a judgement of the information as incomplete, blurred, inaccurate, unreliable, inconclusive or potentially false". This is an inherently subjective perspective on uncertainty. Both Walker et al. (2010) and Refsgaard et al. (2007) relate their definitions of uncertainty to the satisfaction and awareness of the decision-maker. Therefore these definitions include *recognized* ignorance ('known unknowns'), but generally exclude *unrecognized* ignorance ('unknown unknowns')[4]. As this thesis relates to societal decision-making, uncertainty will be interpreted at the societal level (as opposed to discussing it at the level of a single policymaker or organization).

As noted in section 1.1, uncertainties can arise in various steps of the analysis cycle. Even within one step, different sources, locations, natures, and levels of uncertainty can be distinguished. Several typologies of uncertainty and uncertainty-situations have been developed for use in different scientific fields (for relevant discussions, see e.g. Van der Sluijs, 1997; Schneider et al., 1998; Walker et al., 2003; Petersen, 2006; De Vries, 2008; Van der Sluijs et al., 2008; Knol et al., 2009; Kwakkel et al., 2010). A discussion of these is beyond the scope of this introduction, but an example of an uncertainty typology is presented in Table 1.1. This framework is relatively recent and extensive, and gives some overview of the aspects involved.

As Schneider et al. (1998) notes, and is also apparent in the other sources mentioned above, many typologies "expand the conceptualization to recognize that uncertainty is not purely of a technical or physical or biological character, but also social, cultural, and institutional in nature". From a decision-maker's point of view, factors such as value diversity (Table 1.1), ambiguity and frame-diversity (Dewulf et al., 2005; Brugnach et al., 2008, 2011), and public and political preferences regarding goals and options (Van Asselt, 2000) form important uncertainties. These *'societal' uncertainties* (e.g. societal, institutional and political robustness of policy strategies, framing, values, and goals) are often differentiated from the '*scientific' uncertainties* (e.g. ignorance, inexactness, and methodological unreliability). For instance,

[4] Walker et al. (2010) include unrecognized ignorance as a "limiting characteristic" (boundary) of the uncertainty spectrum, opposite to full certainty.

Hisschemöller and Hoppe (1995-1996; 1998) distinguish as two dimensions of policy problems: (a) certainty and consensus regarding the required knowledge, and (b) consensus regarding the relevant norms and values. Similarly, according to Thompson and Tuden (1959; Thompson, 2003) the two basic dimensions of decisions are: (a) beliefs about the cause-effect relations, and (b) preferences regarding possible outcomes. De Marchi (1995) distinguishes scientific uncertainty (uncertainty from the scientific and technical dimensions of a problem) from legal, moral, societal, institutional, proprietary, and situational uncertainty. This thesis includes the latter six under 'societal' uncertainties (interpreted in a broad sense, from a decision-maker's point-of-view). Scientific and societal uncertainties are relevant to distinguish because they can lead to different decision-making strategies and policy approaches.

Table 1.1. Example of an uncertainty typology (application: environmental burden of disease assessment) (Knol et al., 2009; Knol, 2010).

<table>
<tr><th>Uncertainty characterizations</th><th colspan="2">Categories</th></tr>
<tr><td rowspan="4">Location: the location at which the uncertainty manifests itself in the assessment</td><td colspan="2">Context: definitions and boundaries of the system that is being assessed</td></tr>
<tr><td colspan="2">Model structure: structure and form of the relationships between the variables that describe the system</td></tr>
<tr><td colspan="2">Parameters: constants in functions that define the relationships between variables (such as relative risks or severity weights)</td></tr>
<tr><td colspan="2">Input data: input data sets (such as concentrations, demographic data, and incidence data)</td></tr>
<tr><td rowspan="3">Nature: the underlying cause of the uncertainty</td><td colspan="2">Epistemic: resulting from incomplete knowledge</td></tr>
<tr><td rowspan="2">Ontic</td><td>Process variability: resulting from natural and social variability in the system</td></tr>
<tr><td>Normative uncertainty: resulting from a plurality of socioethico-normative considerations within a society</td></tr>
<tr><td rowspan="2">Range: expression of the uncertainty</td><td colspan="2">Statistical (range + chance): specified probabilities and specified outcomes</td></tr>
<tr><td colspan="2">Scenario (range + "what if"): specified outcomes, but unspecified probabilities</td></tr>
<tr><td colspan="3">Recognized ignorance: unknown outcomes, unknown probabilities – uncertainties are present, but no useful estimate can be given</td></tr>
<tr><td colspan="3">Methodological unreliability: methodological quality of all different elements of the assessment; a qualitative judgment of the assessment process which can based on e.g. its theoretical foundation, empirical basis, reproducibility and acceptance within the peer community</td></tr>
<tr><td colspan="3">Value diversity among analysts: potential value-ladenness of assumptions which inevitably involve – to some degree – arbitrary judgments by the analysts. [a]</td></tr>
</table>

[a] In absence of complete understanding, analysts will usually have to make some assumptions (explicitly or implicitly) in order to perform formal analyses such as modeling studies. These are often based on some data or theory – which may or may not be well-established. However, by definition, they always involve some subjectivity. Values (e.g. epistemic, socio-political, worldviews, etc.) can affect these choices to some extent. For instance, when assuming a first-order approximation for a damage function, an analyst who perceives the world as inherently fragile may make a somewhat different choice than an analyst who perceives the world as inherently robust. Such potential value-ladenness can be analysed in order to identify relatively weak links in calculation chains and contribute to explicit choices and uncertainty communication. See Kloprogge et al. (2011).

The typologies also discern different *'levels' of uncertainty*. Walker et al. (2003) discern on a scale from determinism to indeterminacy: *statistical uncertainty* (range of alternative outcomes plus their probabilities), *scenario uncertainty* (range of alternative outcomes, probabilities unknown), and *recognized ignorance* (both range of outcomes and probabilities unknown). See Figure 1.3. Kwakkel et al. (2010) also discern a level of uncertainty in which the range of alternative outcomes can be discerned, as well as an ordinal (rather than probabilistic) assessment of their likelihood; i.e. one is more likely than the other. This level, which they refer to as '*medium uncertainty*', is located in-between statistical and scenario uncertainty. Furthermore, Refsgaard et al. (2007) distinguish 'qualitative uncertainty' from recognized ignorance. Dessai and Van der Sluijs (2007) also introduce the concept of '*surprise scenarios*', which they group with recognized ignorance. This concept has its origins in both the climate change literature ('*imaginable surprises*'[5]; e.g. Schneider, 2004; Schneider et al., 1998) and future studies ('*wildcards*'; e.g. Mendonça et al., 2004; Barber, 2006; Hiltunen, 2006; Steinmüller and Steinmüller, 2004; Smith and Dubois, 2010), and has also been used in financial risk management ('*black swans*'; e.g. Taleb, 2008). Surprise scenarios are hypothetical scenarios for which there is no (or limited) consensus on the plausibility, while there is some scientific evidence to support them. As such, they can be placed in Figure 1.3 between scenario uncertainty and recognized ignorance[6]. However, due to the level of dissensus and knowledge gaps, they relate mostly to ignorance. Often these are envisaged as 'low probability, high impact' events – although 'poorly known probability, high impact' is usually more accurate[7] (Van der Sluijs and Turkenburg, 2006). Surprise scenarios using low impact events may also be constructed, although their policy-relevance may be more limited. Surprise scenarios can be used to assess the sensitivity of the physical/social/policy system to surprise and ignorance.

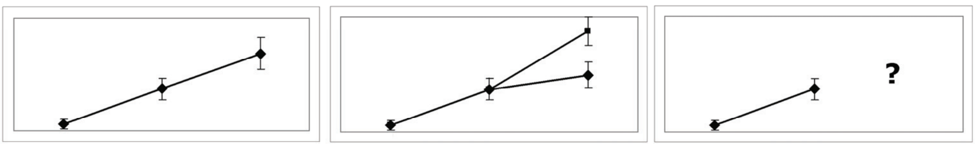

Figure 1.3. Levels of uncertainty (left to right): statistical uncertainty, scenario uncertainty, and recognized ignorance.

[5] Schneider (2004) distinguishes between 'imaginable abrupt events' (i.e. not truly unanticipated) and 'imaginable conditions for surprise' (beyond which truly unanticipated events could take place).

[6] Surprise scenarios share some characteristics with 'normal' scenarios, but are distinct in that they cannot be assumed equally plausible to 'normal' scenarios. Sometimes they are also expressed as gradients (growing more likely with higher temperatures) or imprecise/fuzzy probability ranges; taking on similarities to ordinal and statistical uncertainties.

[7] The perception of surprise scenarios as having a 'low probability' may derive from cognitive bias (cf. the availability heuristic) in some cases, as they are steeped in ignorance, including on their probability. They may be simply more difficult to imagine.

1.3. Climate change adaptation under uncertainty

The large uncertainties and complexities present a challenge for decision-makers on climate change adaptation. For instance, Gagnon-Lebrun and Agrawala (2006) suggest that the level of certainty associated with climate changes and their impacts is often a key determinant for the perceived usability of that information for formulating adaptation responses. Decision-makers who have to make urgent decisions based on highly uncertain information can take various strategies to cope with this situation. One approach is to attempt to 'avoid' uncertainty, e.g. by strictly adhering to existing rules or procedures, or to ignore or avoid the complex issues altogether (Hisschemöller and Hoppe, 1995; De Vries, 2008). For example, one could call for further research on adaptation and wait until uncertainties are reduced. Alternatively, one could focus on those specific impacts that are relatively certain and give considerably less attention to those that are highly uncertain. Inherent assumptions in this approach are that more research will reduce the uncertainties and that time is available to postpone decisions. The tenability of these for climate change adaptation is questionable: more research may in fact unearth even more complexities, thus increasing uncertainty (Dessai and Hulme, 2004; Van der Sluijs, 2005; Trenberth, 2010), and decisions on urban and regional planning (e.g. urban renewal/development, spatial reservations for water) have long-term implications and often cannot be easily changed at a later stage. Another example of uncertainty avoidance is related to the framing of *responsibility* for dealing with the uncertainty (cf. Isendahl et al., 2009). Local governments may avoid the burden of decision-making under uncertainty by shifting responsibility to do so to other agencies, such as the national government, by simply expecting design criteria (e.g. for sewage systems) to be set at that level and following these criteria.

Other approaches can be identified that do explicitly deal with uncertainty, instead of attempting to avoid it: transforming, accepting, or assimilating uncertainty (Van der Sluijs, 2005). Firstly, uncertainty can be interpreted (adapted/transformed) in such a way that it is made to fit the original approach to decision-making. If a single 'true' outcome cannot be computed, than at least this outcome could be represented by a probability or a range. This approach tends to focus on quantification of uncertainties and makes use of tools such as quantitative risk analysis and scenario analysis. The appropriateness of this approach depends on whether enough data is available to adequately perform such analyses and whether the processes involved are understood well enough. It assumes that the topic is relatively surprise-free (i.e. the effect of surprises should be limited compared to the risks or scenarios) and that value-laden assumptions do not play any role of significance (i.e. different models and analysts should reach the same outcomes; cf. Table 1.1). The second approach is to accept, or even embrace, uncertainty and ignorance as a fact of life. Acceptance (without embracement) might lead to including safety margins or options to retrofit policies if necessary. Full embracement would favour holism and inclusive (e.g. participatory) science and decision-making. Uncertainty, for example the full uncertainty space and its potential consequences for the decision, might consequently be used as a prequel to discussing the desired future system and its properties based on broader criteria and considerations than the assessed impacts of (e.g.) climate change. A potential pitfall is that uncertainty might simply be used as a political instrument to further existing agendas. The third approach is to fully assimilate uncertainty into one's conceptualization of the issue and system under study. This would favour 'complex (adaptive) systems' approaches, which deal explicitly with issues such as non-linear system dynamics, surprises and ignorance. A potential disadvantage is the inherent complexity of such an approach, which could make it politically difficult to promote, and considering the potential difficulty of assessing and optimizing matters such as costs, benefits, and efficiency.

The literature is relatively scarce on how the different approaches to dealing with uncertainty mentioned above can actually be applied in the case of climate change adaptation; i.e. how adaptation can cope with uncertainty. Dessai and Hulme (2004) and Dessai et al. (2009a,b) assert that, while climate prediction is limited by fundamental and partly irreducible uncertainties and value judgements, society can make effective decisions by aiming for decisions that produce satisfactory, rather than optimal, results. Exploratory modelling (cf. Bankes, 1993) and *robust decision-making* could be used to create a better understanding of climate-related vulnerabilities and how to address these. Robust strategies would perform well under a wide range of assumptions regarding the future. In an early position paper, Peterson et al. (1997) assess that, due to the uncertainty and complexity, climate change presents policymakers with novel situations, and that coping with these requires a capacity to learn. They argue that an approach of *adaptive management* should be taken, because knowledge on such an uncertain issue should be continually updated and challenged. Adaptive management utilizes policy-based experimentation; developing alternative hypotheses, indentifying gaps in knowledge, and assessing what knowledge would most effectively distinguish alternative hypotheses. Consequently, scientists would need to actively address, explore and communicate uncertainty, and scientific dissent and the limits of scientific knowledge should be acknowledged. Successful adaptation under uncertainty requires improved communication between developers and users of climate change information, tailoring to decision-makers' information needs, clear identification of underlying assumptions and uncertainties addressed in the information, and appropriate user guidance (Goodess, et al., 2007). Van der Sluijs and Turkenburg (2006) propose a *precautionary approach* to climate risk management, and suggest to enhance monitoring and empirical research on detection and early warnings and to focus risk management strategies on robustness, resilience, and vulnerability.

Hallegatte (2009) indicates five methods to enhance the robustness of policies: (a) selecting no-regret strategies, (b) favouring reversible and flexible options, (c) creating safety margins, (d) promoting soft adaptation strategies, and (e) reducing decision time-horizons. The negative and positive side-effects and externalities of adaptation decisions, including adaptation-mitigation interaction, should be considered as well.

Charlesworth and Okereke (2010) argue that current policy responses do not adequately address the possibility of rapid climatic changes, because they make unwarranted assumptions regarding the predictability of climate change, including tipping points, and are based on utilitarian ethical assumptions (optimization, using e.g. cost-benefit analysis and similar approaches) that are likely not shared unanimously. They highlight several approaches that do not strongly rely on prediction: incremental adaptive approaches, robust decision-making, reducing pressure on the earth system, the precautionary principle, virtue ethical approaches (emphasizing moderation, prudence, and hope), and discursive democracy. In the similar context of imaginable surprises, Schneider et al. (1998) recommend that several presently underutilized approaches should be encouraged: (a) backcasting scenarios, to explore alternative ways in which proposed events and processes might happen; (b) increased attention for the study of 'outlier outcomes'; and (c) exploring the *'resilience' paradigm* alongside the *'optimization' paradigm*. They also argue that alternative and unconventional views in the scientific community should be given due (but not uncritical) attention in research and communication.

Related to Schneider et al.'s third suggestion, Dessai and Hulme (2004) and Dessai Van der Sluijs (2007) and argue that two schools of thought have emerged on how to deal with climate change uncertainty in adaptation: the prediction-oriented 'top-down' approach and the resilience-oriented[8] 'bottom-up' approach. The prediction-oriented approach starts from the global level, analyzing world development, its consequences for global change, and ultimately their impacts on the local system. This school, originating in the classic risk analysis and (economic) policy analysis literatures, aims at characterizing, reducing, and managing uncertainties. The resilience-oriented school analyzes the affected system and its components to assess its vulnerability to local and global changes. Originating in the literatures on societal/policy learning and complex adaptive systems, it emphasises learning from the past, and learning to live with uncertainties and internalizing them in the policy measures taken. Dessai and Van der Sluijs (2007) link these two schools to 'conventional' versus 'adaptive' attitudes on policy analysis (Walters, 1986). The former focuses on precise predictions, consensus, and optimization. The latter on exploring the range of possible futures, plural perspectives, imagination and novel

[8] Note that both resilience and adaptive management are used both as paradigms/metaphors (broad meaning; way of looking at things) and as operational management principles (more precisely defined) in the literature. Resilience-oriented and adaptive will indicate the paradigms; resilience (approach) and adaptive management the management principles.

strategies, and profiting from change. Similarly, Pahl-Wostl et al. (2011) discuss two paradigms in water management: predict & control and integrated & adaptive. The two schools of thought lead to different adaptation strategies under uncertainty, such as risk and scenario analysis (prediction-oriented), and adaptive management and anticipating design (resilience-oriented). These strategies have different capacities to cope with various levels of uncertainty; see Table 1.2.

Table 1.2. Qualitative indication of how well various adaptation frameworks deal with three levels of uncertainty, according to Dessai and Van der Sluijs (2007). Legend: ++ very good, + good, ± somewhat, - bad, -- very bad.

	Frameworks for decision making under uncertainty	Statistical uncertainty	Scenario uncertainty	Recognized ignorance & surprises
a	IPCC approach	+	++	--
b	Risk approaches	++	+	--
c	Engineering safety margin	++	±	-
d	Anticipating design	++	+	+
e	Resilience	±	+	++
f	Adaptive management	++	-	--
g	Prevention Principle	++	±	--
h	Precautionary principle	+	++	++
i	Human development approaches	±	+	+
j	Adaptation Policy Framework	+	+	+
k	Robust decision making	+	++	+

See e.g.: [a] Carter et al. (1994); [b] Willows and Connell (2003); [c] Van Beek (2009); [d] Dessai and Van der Sluijs (2007); [e] Chapter 3 and Barnett (2001) and De Bruin (2004a,b); [f] Holling (1978) and Arvai et al. (2006); [g] De Sadeleer (2002); [h] UNESCO COMEST (2005); [i] Burton and Van Aalst (1999) and Kelly and Adger (2000); [j] Burton et al. (2002); [k] Dessai (2005) and Groves and Lempert (2007).

1.4. Focus and scope of this thesis

The literature on climate change adaptation under uncertainty, as discussed above, is scarce at best. A handful of papers assess this topic, generally based on insights from studies on specific adaptation approaches – which have sometimes developed as fields of study in their own right. Mostly, this information deals with adaptation under uncertainty only cursory, e.g. noting that the approach is helpful in one or another way in coping with uncertainty. Few of the underlying studies specifically address the topic. Notable exceptions are the approaches of robust decision making (mostly on water resources management) and adaptive management (particularly on water management and nature conservation). This thesis builds mainly on the 'scoping study' by Dessai and Van der Sluijs (2007).

The study of climate change impacts and adaptation under uncertainty is a developing field with limited empirical and conceptual work already performed. This thesis aims to strengthen the empirical basis of this field, in order to improve its theory and practice. Primarily, this thesis explores climate change adaptation under uncertainty in practice by means of several case-studies, in the context of the theoretical/conceptual literature. The main research question is:

- How do the conceptual and theoretical insights from the literature apply in the practice of climate adaptation under uncertainty; and how can uncertainty better be taken on board in climate change adaptation and interaction between science and policy on this topic?

Three main case-studies are discussed as separate chapters (Chapters 2-4) in this thesis. They cover different situations in the frameworks regarding the scientific versus social uncertainties, discussed in Section 1.2. See Table 1.3 below. The first study ('health impacts') focuses on the uncertainties regarding climate change impacts on public health, and relates these to policy implications. In this case-study, the preferences regarding outcomes and norms and values are clear: public health is an important issue and its protection is an undisputed priority in the policies of many nations. The case is however associated with huge complexity and ignorance: for most impacts, quantitative assessment is currently difficult or impossible, and cause-effect relations are often murky. The second case-study ('resilience Rotterdam') presents a climate impacts and adaptation assessment, focusing on both the science and policy sides. This case is more difficult to place in the literature's societal vs. scientific dichotomies. On the one hand, it fits into low uncertainty on both axes: many of the dominant impacts (e.g. sea level rise, river discharge) and cause-effect relations are relatively well-understood and agreed upon, and the municipality of Rotterdam's goals (to establish a strong economy and attractive city; Rotterdam.dS+V, 2007) are also clear. On the other hand, the exact local implications for the case-study area, the areas outside the dike-defense zones, were perceived as highly uncertain, several surprise scenarios were plausible and would strongly affect climate change impacts, and the municipality did not have a clear view of how to adapt in this area at all. The third main case-study ('ethics & US religious groups'), on the debate among religious groups on climate change, focuses on the political/policy side of climate change, which is partly based on perceptions regarding impacts. While there are differences in opinion regarding the strength of the available knowledge and regarding cause-effect relationships between some of the groups, the fundamental debate is mainly about ethics and values. Therefore, the case is taken as an example of high societal uncertainty and plurality of perspectives on what knowledge is relevant.

Several other case-studies have contributed to this thesis as well, but have not been published as stand-alone scientific articles: a study on dealing with uncertainty in the advice of the Deltacommittee 2008 (Wardekker et al., 2011), a joint workshop with the Province of Groningen regarding framing and the Provincial Environment Plan (Buijen et al., 2008), and an analysis of the book/movie "An Inconvenient Truth" (unpublished). These cases are briefly discussed in Chapter 6.

The final two chapters focus on the science-policy interface. If decision-makers are expected to develop strategies that can cope with climate change uncertainties, and are tailored to the specific uncertainties involved, these uncertainties will need to be adequately communicated, in a form that is useful to the decision-makers. Chapter 5 therefore focuses on uncertainty communication in the science-policy interface. In Chapter 6, the results of the case-studies are reconnected to the literature on decision-making under uncertainty. The chapter explores the different ways in which climate change adaptation can be framed, and how this relates to decision-making strategies, structures, and tools and knowledge needs.

Table 1.3. The relation of the main case-studies with different uncertainty-situations.

Scientific uncertainty:	**Societal uncertainty:**	
	Low	**High**
Low	Resilience Rotterdam (regional)	Ethics & US religious groups
High	Health impacts	Resilience Rotterdam (local)

Chapter 2: Health impacts. This chapter discusses the level of uncertainty involved in numerous potential health impacts of climate change in the Netherlands. It also presents some results on uncertainty-proof adaptation strategies as supplementary material. The chapter itself discusses the consequences for adaptation based on the theoretical literature. The central question is: What levels of uncertainty are associated with the health impacts of climate change? What does this imply for adaptation strategies?

Chapter 3: Resilience Rotterdam. The application of a resilience approach to climate change adaptation is assessed for the urban areas outside the dike-defense zones in Rotterdam. The chapter contains an impact assessment for the area and an analysis of adaptation options based on ‘resilience principles’. It concludes with a discussion on these principles and on the ability of this adaptation approach to cope with uncertainty. The central question is: How can a bottom-up concept such as resilience be operationalised into potential adaptation measures in a local context?

Chapter 4: Ethics & US religious groups. This chapter presents a discourse analysis of the debate among religious groups in the United States on climate change. While the topic is much broader than impacts and adaptation, also strongly dealing with mitigation policy, it is relevant for this thesis due to the centrality of values and ethical issues and arguments in this debate. The central question is: How do differences in values and outcome preferences emerge in societal debate on climate change?

Chapter 5: Uncertainty communication. This chapter discusses uncertainty communication in environmental reporting in the context of an evaluation study of the communication in the Netherlands Environmental Assessment Agency’s

Environmental Balance 2005. Topics such as policymakers' perceptions of uncertainty, their knowledge needs, and the usability and pitfalls of various presentation formats are covered. The central question is: What does uncertainty mean to policymakers and how can it be communicated effectively in the context of environmental assessment?

Chapter 6: Frame-based guide to situated decision-making. Returning to the theoretical literature, this chapter discusses different framings of climate change impacts and adaptation, using the case-studies as examples. These different frames are then related to different decision-making approaches, and the decision-making and knowledge-generation tools that would best fit the policy situation. The central question is: How can 'adaptation & uncertainty' be framed in a science-policy context and what does this imply for the suitability of decision-tools?

Chapter 7: Summary and conclusions. This final chapter (in English and Dutch) brings together the overall results of the previous chapters and briefly reflects on the implications of these in the light of the theoretical literature.

Chapter 2.

Uncertainty and health risks of climate change: Results of an expert elicitation for the Netherlands

Abstract
The predictability of impacts of climate change on human health is limited by uncertainty. Planned adaptation requires a profound understanding of these uncertainties. We aim to elicit insights on the levels of uncertainty for various conceivable health effects of climate change and to explore implications for adaptation strategies. A formal expert elicitation was performed through an in-depth questionnaire. Experts were asked to indicate the level of precision with which health risk estimates can be made, given the present state of knowledge. The direction of change could be indicated for most anticipated health effects. For several potential effects, too little knowledge exists to indicate whether any impact will occur, or whether the impact will be positive or negative. For several effects, rough 'order-of-magnitude' estimates were considered possible. Factors limiting quantifiability include: lacking data, multicausality, unknown impacts considering a high-quality health system, complex cause-effect relations leading to multi-directional impacts, possible changes of present-day response-relations, and difficulties in predicting local climate impacts. Given the present state of knowledge, the scope for predict-and-prevent adaptation approaches seems very limited. Enhancing resilience, flexibility (of policy measures or healthcare/society in general), and adaptive capacity seems more suitable for most health effects. We recommend assessing the availability of no-regret options and the opportunities and risks of precautionary measures. For effects for which rough health risk estimates are feasible, there may be some scope for applying robust decision-making.

J. Arjan Wardekker, Arie de Jong, Leendert van Bree, Wim C. Turkenburg, Jeroen P. van der Sluijs

Submitted for publication.

2.1. Introduction

Climate change is projected to have wide-ranging effects on physical, ecological and societal systems. Conceivable health-related impacts include changes in temperature-related mortality, malnutrition, infectious diseases, environmental quality, natural disasters, and societal stability (Haines et al., 2006; IPCC, 2007b; Costello et al., 2009).

Assessments of climate change impacts involve uncertainty in every step of the analysis, from assumptions about socio-economic developments and their implications for future global and local climates, to projections of local impacts of climate change. These add-up in a ‘cascade’ of uncertainty (Dessai and Van der Sluijs, 2007). Health risks arise from the interaction of uncertain future climatic changes with complex ecological, physical, and socio-economic systems, which are simultaneously affected by numerous other changes (e.g. globalisation, demographic changes, and changes in land use, nutrition, health care quality). Adaptation policymaking thus faces substantial uncertainties.

Health impact assessments of climate change frequently indicate uncertainties. Examples include: 95%-confidence intervals for exposure-response relationships (e.g. temperature-mortality), geographical and temporal variability, ranges of published climate scenarios, co-existence of equally plausible model structures, differences between impact assessments due to different underlying assumptions, limited available empirical data, questions regarding the applicability of short-term historical relationships to long-term projections, biases, multi-factorial causal webs, confounders, non-linear responses, and various knowledge gaps (McMichael et al., 2004; Patz et al., 2005; MNP, 2006; IPCC, 2007b; Huynen et al., 2008; Xun et al., 2010; Kolstad and Johansson, 2011). Such uncertainties extend far beyond confidence intervals and similar metrics, which represent only statistical uncertainties and may not include all relevant (or even key) factors and parameters (Forastiere, 2010). Deeper levels of uncertainty limit the reliability of health risk assessments of climate change (cf. Walker et al., 2003).

Some approaches to climate adaptation can handle certain levels of uncertainty better than others (Dessai and Van der Sluijs, 2007). For example, quantitative risk approaches handle statistical uncertainties well, but fail to tackle deeper levels of uncertainty. Resilience-oriented approaches, on the other hand, can cope well with ignorance and surprises, but are less suitable when statistical uncertainty prevails. Thus, the level of uncertainty and its nature have important implications for the suitability of adaptation approaches and for policy choices regarding its implementation.

While uncertainty is frequently discussed in the literature on climate and health, this information is spread over multiple research fields. Synthesis documents do provide information on major sources of uncertainty and knowledge gaps, but not on the *level* of uncertainty, nor on differences among effects/topics (i.e. are we more ignorant about one effect than another?). Expert elicitation could provide this information. This paper investigates the level of uncertainty for various conceivable health impacts of climate change, using the ‘Level of Precision’ scale developed by Risbey and Kandlikar (2007) (Table 2.1); ranging from ignorance to probabilistic estimates. This scale allows for an ordinal comparison between health effects. Policy implications of this uncertainty assessment will be discussed.

2.2. Methods

2.2.1. Setup

A formal expert elicitation was performed to assess the levels of uncertainty associated with conceivable health impacts of climate change in the Netherlands, and their implications for climate change adaptation. Expert elicitation is a structured approach of consulting experts on a subject where there is insufficient knowledge in the published literature. It seeks to make explicit and synthesise the published and unpublished knowledge and insight of experts (Cooke, 1991; Knol et al., 2010), including limitations, strengths and weaknesses of published knowledge and available data. Multiple steps can be discerned (see Supplementary Material). Literature analysis, inventorying relevant subtopics and uncertainties, provides the basis for the elicitation’s design and scope. A list of relevant health effects was drafted based on recent Dutch impact assessments (MNP, 2006; Huynen et al., 2008; GR, 2009).

Knol et al. (2010) review methods and approaches to expert elicitation such as workshops/panels, face-to-face interviews, or questionnaires. Our study used an online, in-depth questionnaire, because of the broadness and fragmented nature of the field of ‘climate change and health’, and preference for a standardized format.

The study focused on the Netherlands to prevent biases due to possible local/regional differences in predictability and uncertainty. Additionally, the outcomes may provide inputs for national-level assessments, such as the further development of a ‘roadmap to a climate-proof Netherlands’ (PBL, 2009b).

Participants were given the opportunity to comment on this paper before it was submitted.

2.2.2. Expert selection

External experts with good overviews of the networks of Dutch, Belgian, and European researchers were provided with the questionnaire and background information, and were asked to nominate experts with sufficient relevant knowledge to assess the questions posed (explicitly on climate & health, uncertainties, and adaptation). The resulting list was invited; the invitation included a suggestion to forward it to additional relevant experts. The list included scientists and knowledgeable professionals. A total of 21 experts participated (see Supplementary Material). Responses were submitted during June-September 2009. Individual quantitative questions were answered by 8-17 experts each (mean: 12.6). This is well within the range that is usually aimed for in expert elicitations (6-12; Cooke and Probst, 2006; Knol et al., 2010).

Participants were asked to indicate their areas of expertise, allowing a distinction between generalists and subject-matter experts on specific questions. They were instructed to answer only those questions that they considered themselves capable of assessing. All health themes were assessed by subject-matter experts; 1-5 (mean: 3.1) per theme. Expertises 'adaptation' and 'health and adaptation' were represented by 8 and 6 subject-matter experts respectively. Expertises were used in weighting and interpreting the results, particularly to uncover any discrepancies between generalist and subject-matter expert scorings and arguments.

2.2.3. Protocol and analysis

The questionnaire (see Supplementary Material) used both quantitative and qualitative questions, often using a scoring scale (Level of Precision, Table 2.1) or rank-order of a health effect followed by argumentation. Argumentations were important for understanding and analyzing the scores, and to stimulate active reflection on the available evidence by the participant in the process of scoring. Responses to qualitative questions were analysed for lines of argument, and for similarities, differences, biases and consistency of these (within and between questions and scores).

The main part of the questionnaire investigated the level of uncertainty associated with the various health impacts. The experts were asked: "*Regarding the following specific health issues, with what level of precision would you be able to estimate the magnitude of the health risk for the Netherlands (due to climate change)? Assume you would be given some time to review the relevant literature, before you would make the effect estimate.*" The question did not consider a single climate scenario (although respondents may have interpreted it as such). When an expert answered with a range, his vote was equally divided over these scores. Group scores were created using the weighted median and interquartile range of individual scores. Subject-matter experts were given double weight.

The questionnaire's second part focused on policy implications. Participants were asked to indicate and rank the five health effects they considered most 'relevant' for Dutch climate adaptation policy in view of health. The questions concerning adaptation options are discussed in the Supplementary Material. Final scores were created per effect; assigning 5 points for each time selected as most relevant, 4 points for second-most relevant, et cetera. Final scores were grouped into four classes (I: 0 points, II: 1-10 points, III: 11-20 points, IV: ≥21 points) to prevent an unwarranted level of resolution, considering the number of respondents to this question (n=16) and potential bias of experts towards rating their own fields as particularly relevant.

Table 2.1. Level of Precision scale (based on Kandlikar et al., 2005; Risbey and Kandlikar, 2007).

Score:	Label:	Description:
1	Effective ignorance	Knowledge of the factors that govern this effect is so weak that we are effectively ignorant.
2	Ambiguous sign or trend	Some effect is expected, but its sign or trend is not clear. There are plausible arguments either direction (effect could be positive, could be negative; could increase or decrease).
3	Expected sign or trend	It is clear what the sign and trend of the effect will be. However, there is no plausible or reliable information on how strong it will be.
4	Order of magnitude	It is possible to give a rough indication of the magnitude of the effect, a qualitative scoring (e.g. 1-10 scale), or a rough comparison with other effects.
5	Bounds	It is possible to estimate the bounds for the distribution of the effect, e.g. its 5/95 percentiles (effect is only 5% likely to be more than … and only 5% likely to be less than …). However, the shape of the distribution, or best-guess estimates, cannot be provided.
6	Full probability density function	It is possible to provide a full probability density function; the bounds as well as the shape of the distribution.
N/A	Don't know / no answer	

2.3. Results

Level of precision scores (Table 2.2) are discussed per health theme. The final section discusses the relevance of health effects for adaptation.

2.3.1. Temperature

Changing temperatures may affect premature mortality and morbidity through effects on cardiovascular and respiratory diseases, or various indirect effects (e.g. drought-related increase pollutant-concentrations, dehydration). In terms of achievable precision of impact assessment, heat-related mortality received the highest-score in this study: median 4 (interquartile 4-5). Cold-related mortality scored 4 (3-4).

Regarding heat-related and cold-related mortality, respondents noted that much data, experience, and literature is available. One generalist, scoring heat-related mortality at ‘full PDF’, suggested that it shouldn’t be difficult to “tune a model for mortality surveillance or expected mortality”. Most experts, however, indicated that projections based on present-day epidemiological evidence are limited by:

- limited data for the Netherlands (cf. Huynen et al., 2001; temperature-mortality relation is based on only six heat waves and five cold spells),
- confounders and interactions with other changes (e.g. socio-economic, air quality, demographics, harvesting effect),
- possible changes of the response function (e.g. physiological adaptation, behavioural changes, changes in building practices such as availability air conditioning),
- limited knowledge on why response functions differ across places,
- difficulties in assessing future heat wave intensity, duration, and frequency,
- limited knowledge on the (biophysical) ‘why’ of heat-related mortality and precise metrics which are causally linked to the effect.

One subject-matter expert scored cold-related mortality at ‘ambiguous sign/trend’, suggesting that it could increase, rather than decrease, under some climate scenarios and assumptions on autonomous adaptation, although only one study (Huynen, 2008) has demonstrated this. The cited study does, however, provide order-of-magnitude estimates of these cases.

For temperature-related diseases, most participants indicated that the effects of (changing) temperature(s) were well-documented in literature, particularly for the elderly, but data (in general and Netherlands-specific) is lacking to make reliable order-of-magnitude assessments. For respiratory problems, the interaction with hay fever and air quality effects was mentioned as confounders. Arguments for higher scores referred only to the availability of literature and epidemiological data, such as on the 2003 European heat wave. For cold-related diseases, one subject-matter expert (scoring 1) noted that it is still unclear why influenza is a seasonal disease.

Regarding indirect effects, many respondents pointed to a lack of data, although there are some indications that climate change may affect these issues. Arguments for low scores suggested that it was unclear whether health impacts would take place, considering the well-prepared societal care system. Arguments for high scores indicated existing reports/modelling and the availability of short-term abatement options that would limit impacts (providing a constraint for the estimate).

Table 2.2. Scoring for the 'Level of Precision' with which climate change-related health risks for the Netherlands can be assessed (see Table 2.1 for scoring scale).

Health effect	Level of Precision							
	Frequency/score[a]						Median[b]	Inter-quartile[b]
	1	2	3	4	5	6		
Temperature								
1. Heat-related mortality				9 (2)	3 (1)	2	4	4-5
2. Heat-related cardiovascular problems		½	9½ (2)	3	1 (1)	1	3	3-4
3. Heat-related respiratory problems			11 (2)	3	2 (1)		3	3-4
4. Heat-related stress and sleep disturbance		1 (1)	8 (2)	5			3	3-4
5. Cold-related mortality		3 (1)	2	7 (1)	2 (1)	1	4	3-4
6. Cold-related diseases	1 (1)	2	7 (1)	3	2 (1)		3	3-4
7. Drought-related exposure to contaminants		5 (1)	6 (1)	2			3	2-3
8. Shortages of drinking water		3 (1)	3	5 (1)		1	3½	2¼-4
9. Dehydration		5 (1)	5 (1)	3	1 (1)		3	2-4
Allergies								
10. Asthma	1	4	7 (4)	1			3	2-3
11. Allergic eczema	1	5 (1)	3 (1)				2	2-3
12. Hay fever: duration of pollen season			10 (4)	2 (1)	3		3	3-3½
13. Hay fever: pollen types, abundance and allergenicity		1	10 (5)	2	2		3	3
Pests								
14. Wasps	1	3 (1)	2 (1)	1	1		2½	2-3
15. Oak processionary caterpillar			1	8 (2)	2		4	4
Vector-borne diseases								
16. Native vector-borne diseases		7 (3)	4 (1)	5 (1)	1		3	2-4
17. Incidents of non-native vector-borne diseases	1¼ (¼)	5¼ (2¼)	5¼ (2¼)	4¼ (¼)			3	2-3
18. Epidemics of non-native vector-borne diseases	1¼ (¼)	6¾ (2¼)	4¾ (1¼)	2¼ (¼)			2½	2-3
Food/water-borne diseases								
19. Food poisoning	1	1	6	5 (1)			3	3-4
20. Legionnaires Disease		2	7	2 (1)	1		3	3-4
21. Contamination of swimming/recreation water			4	7 (1)	1		4	3-4
Air quality-related								
22. Respiratory problems due to ground-level O_3		1½	4½	4 (2)	2 (1)		4	3-4
23. Respiratory problems due to PM		1½	3½	3 (2)	2 (1)		4	3-4
24. Air quality-related cardiovascular problems		2	3	3 (2)	2 (1)		4	3-4
Flooding/storm								
25. Flood-related mortality		4	2	2½ (½)	3½ (1½)		4	2¼-4⅞
26. Flood-related infectious diseases		5 (1)	5 (1)	1			3	2-3
27. Flood-related exposure to dangerous substances and contaminants	1	5 (2)	3	2			2	2-3
28. Flood-related respiratory problems	1	3	5 (1)	1 (1)	1		3	2-3
29. Flood-related mental health problems		2	7 (2)	1			3	3
30. Storm-related mortality and injury		3	3 (2)	4	1		3	3-4
UV-related								
31. Cataract	1 (1)	3	1	1	3 (2)		3½	2-5
32. Skin cancer	1 (1)	3	2	2	4 (2)		4	2-5
33. Weakening of the immune system	2 (1)	3	1	2 (1)	1 (1)		2½	1¾-4

[a]Total experts/score; subject-matter experts are indicated between parentheses. [b]Weighted.

2.3.2. Allergies

An increasing growing/blooming season, and changes in relative humidity may have implications for e.g. (aero)allergens, particularly pollen, and house dust mite allergen. This would affect health through changes in asthma, allergic eczema and hay fever. Allergic eczema scored 2 (2-3); asthma 3 (2-3) and hay fever-effects 3 (3-3 and 3-3½).

Regarding asthma and allergic eczema, subject-matter experts indicated that negative effects can be expected, due to the expected impacts of climate change on hay fever. However, asthma is a highly multi-factorial/multi-causal disease and there is a lack of data, particularly for the Netherlands. The magnitude of health impacts under various climate scenarios was deemed unclear. Arguments for 'ambiguous sign/trend' are similar; multiple causes of asthma may have different signs and it is unknown which will dominate. One generalist suggested that effects could be different, possibly opposite, in summer and in winter; the "time integration" is therefore uncertain.

Participating experts deemed climate health impacts via hay fever likely through increase in the length of the pollen season and promoted spreading of new, highly allergenic plants (e.g. ambrosia/ragweed, spreading pellitory, olive tree). Indications exist that climate-related factors affect pollen allergenicity and abundance. However, data is sparse and the interplay of relevant factors and magnitude of impacts were seen as unclear. Observed effects differ per plant species and pollen counting station. Furthermore, the effect of longer pollen seasons on the duration and intensity of exposure is unclear, allergy is multi-factorial, and the impacts largely depend on the response of patients, medication use, and the medical sector (e.g. knowledge development and communication).

2.3.3. Pests

Climate change may affect health-related pests, such as wasps (stings, allergic reactions) and the oak processionary caterpillar (airborne urticating hairs). They scored 2½ (2-3) and 4 (4-4) respectively.

Two respondents, scoring wasps at 2, noted that in recent years, queen wasps woke up earlier in spring after hibernation due to high temperatures in winter and early spring. Combined with good weather conditions during the most vulnerable phase (April), this resulted in increased numbers of wasp nests and wasps. However, frequent warm winters might also reduce winter survival when hibernation is disturbed during a warm episode that is followed by a colder episode. Higher scores were justified by "recent observations".

The oak processionary caterpillar entered the south of the Netherlands in the 1990s and gradually spread north. Respondents expected a further spread and significant increase in population size due to climate change. Rough disease estimates exist, but the exact potential future magnitude is unknown.

2.3.4. Vector-borne diseases

Endemic (primarily Lyme disease) and non-endemic vector-borne diseases may be affected by climate change. The survey distinguished between incidents and epidemics: some likely cannot become epidemic (e.g. because they are easily countered by a well-equipped health care system). Endemic diseases scored 3 (2-4), non-endemic 3 (2-3) and 2½ (2-3).

Respondents noted that changes in temperature and relative humidity affect ticks and insects. Lyme incidence has strongly increased in recent years, but many respondents stressed that recent changes were not solely, or even not mainly, caused by climate change. Arguments for 'ambiguous sign/trend' (2) included the short period of data for the Netherlands, the multifactoriality (e.g. trends in socio-economic factors, land use, contact with vectors, recreation, global travel/trade, welfare, health care), and the unclear effect of climate change on a complex transmission cycle and disease ecology. A subject-matter expert noted that climate change is unlikely to have unidirectional effects on the complex interactions between vectors, reservoirs, humans, and their environments. Arguments for a score of 3 are similar. One subject-matter expert noted ongoing research indicating a longer activity season for ticks in the Netherlands, during warm winters. The subject-matter expert scoring 4 suggested that some data exists and rough estimations could be made.

Arguments for non-endemic diseases are similar. Those scoring 2 argued that many non-climatic factors are likely more important, that the complexity of the diseases makes unidirectional impacts unlikely despite the sensitivity of biological processes to climate. Those who scored 3 acknowledged these difficulties but argued that the risks may increase due to more favourable conditions (particularly for incidental occurrence). One subject-matter expert scored 1-4, noting that the scoring would differ per disease. The arguments seemed to suggest that impacts on some diseases could be considered negligible because other factors presumably dominated disease risks, while for others the effects would be highly uncertain. For epidemics, some respondents shifted to lower scores, adding that this would be dependent on even more variables than incidents.

2.3.5. Food- and waterborne diseases

Climate change impact on contamination of swimming/recreation water (e.g. cyanobacteria) scored 4 (3-4); other food- and waterborne diseases 3 (3-4).

Regarding food poisoning, arguments for 'expected sign/trend' noted a potential effect, but indicated that many other factors (e.g. hygiene codes, refrigeration) determine whether this increases risks. Arguments for 'order-of-magnitude' suggest that there is much data on the present relation between temperature and food poisoning, particularly for Salmonella, and that models for impact assessment are available.

For Legionnella, one subject-matter expert, scoring 4, indicated that data and models exist and rough estimates could be made. The majority of generalists, scoring 3, suggested that this effect is related to warm water systems the climate impact on these is unclear, and that this depends on the water distribution systems infrastructure and (autonomous) adaptive capacity.

Regarding contamination of swimming/recreation water, those scoring 4 referred again to the existence of models and data. Those scoring 3 highlighted uncertainties such as the precise nature, extent, and speed of impacts, disease incidence, and changes in the amount of water in urban areas.

2.3.6. Air quality

Temperature and other weather conditions influence air quality, such as ozone (O_3) and particulate matter (PM) concentrations. These effects were scored 4 (3-4).

High scores (4+) were justified by known exposure-response relationships of air pollution, and by availability of many data and assessment models. However, estimating the effect of climate change on pollutant concentrations, and speed of changes, was deemed difficult. One subject-matter expert noted that population vulnerability is temperature-dependent and might therefore also change. Lower scores (2-3) pointed out that concentrations of ozone precursors might change, countervailing effects exist, and the “time-integrated sign of change” of pollutants was deemed unknown. The latter may refer to summer versus winter effects.

2.3.7. Flooding and storms

Storms and changes of flooding, due to sea level rise and increased river peak discharges, may have health consequences. Flood-related mortality scored notably wide: 4 (2¼-4⅞). Exposure to contaminants scored 2 (2-3).

For flood-related mortality, arguments for ‘bounds’ (5) estimates indicated that many data and models are available, and that we have sufficient experience to estimate this risk. One respondent, scoring 4-5 suggested that scenario-based bounds estimates could be made, but that he would be sceptical about these, because they depend on many assumptions and less quantifiable variables. A respondent scoring 4 estimated that the effects would remain low due to a good evacuation infrastructure and ongoing water-related adaptation. An expert scoring 2 indicated not to know of any “records” on flood-related health impacts of climate change, and that flood-intensity depends on, and is likely dominated by, many non-climatic factors.

Regarding flood-related infectious diseases and exposure to contaminants, respondents scoring 3 noted that some data and models are available. The risk of sewage overflows could increase, thus increasing disease risk. Those scoring 2 stated that knowledge on flood-related infections is mainly from disasters abroad, particularly from developing countries not representative for the Netherlands where the emergency and healthcare system differs.

Flood-related respiratory problems could occur due to moulds in damp homes. Those scoring 3 assessed that it is difficult to translate increased flood risks to additional home dampness and the effects thereof. A subject-matter expert scoring 4 stated that some estimates regarding the current dampness situation do exist.

Studies have shown mental health impacts following floods and evacuations. However, most respondents maintained that the available data is insufficient to make estimations for the future.

Concerning storm-related mortality and injury, most respondents noted that expected changes in storm climate due to climate change are relatively small and highly uncertain, and data is lacking on the effects on mortality and injury. A respondent scoring 5 suggested that data is available and can be extrapolated.

2.3.8. UV

Climate change may indirectly affect exposure to UV-radiation, for example via changes in cloud cover, ozone-fluxes, and behaviour (e.g. recreational), or due to slowing the recovery of the ozone layer. Respondents were strongly divided over the level of precision.

Two lines of reasoning could be discerned. Arguments for low scores indicated that interactions between climate change and ozone/UV are highly complex, uncertain, and dependent on many other factors. Conversely, arguments for high scores posited that data is available from countries with climate conditions similar to that projected for the Netherlands. Furthermore, good models are available for impact assessment. The main contention seemed to be whether future exposure estimates can be constructed. Some argued that they cannot, while others assessed that they can be extrapolated from present data. Weakening of the immune system scored lower than cataract and skin cancer; one respondent indicated that the effects of UV-radiation on the immune system are uncertain.

2.3.9. Relevance of health effects for adaptation

Heat-related mortality (effect 1) and incidents of non-endemic vector-borne diseases (effect 17) scored highest on relevance. Both were categorised in ‘relevance class’ IV (Figure 2.1). Interestingly, they differ strongly in their level of precision. Other relevant effects (class III) were: non-endemic epidemics (18), heat-related cardiovascular and respiratory problems (2-3) and hay fever (12-13). The arguments for these effects are discussed below (other effects: see Supplementary Material).

Regarding heat-related mortality, respondents indicated that nursery homes, houses, and urban planning are currently not adapted to high temperatures at all. Other reasons for its relevance include: political interest, public perception, possible stress on the health care system, current lack of interest in this topic in the health care sector, the many people at risk, and the potential for many victims in a short time-period. Regarding heat-related cardiovascular and respiratory problems, participants noted that effects could be substantial, and that many other risk factors could enhance the impact (e.g. traffic, city design, obesity, diabetes).

Regarding non-endemic vector-borne diseases, respondents noted that the impacts could be substantial and difficult to adapt to, and referred to public perception ('fright factors' and public unrest). Incidents could be difficult to recognize, and epidemics could place stress on the health system.

Concerning hay fever, respondents pointed to the large number of people affected, considering present-day hay fever incidence. Impact, in terms of health and economic damage (e.g. decreased worker productivity), could be large. For pollen types/abundance/allergenicity, it was noted that effects could be difficult to adapt to.

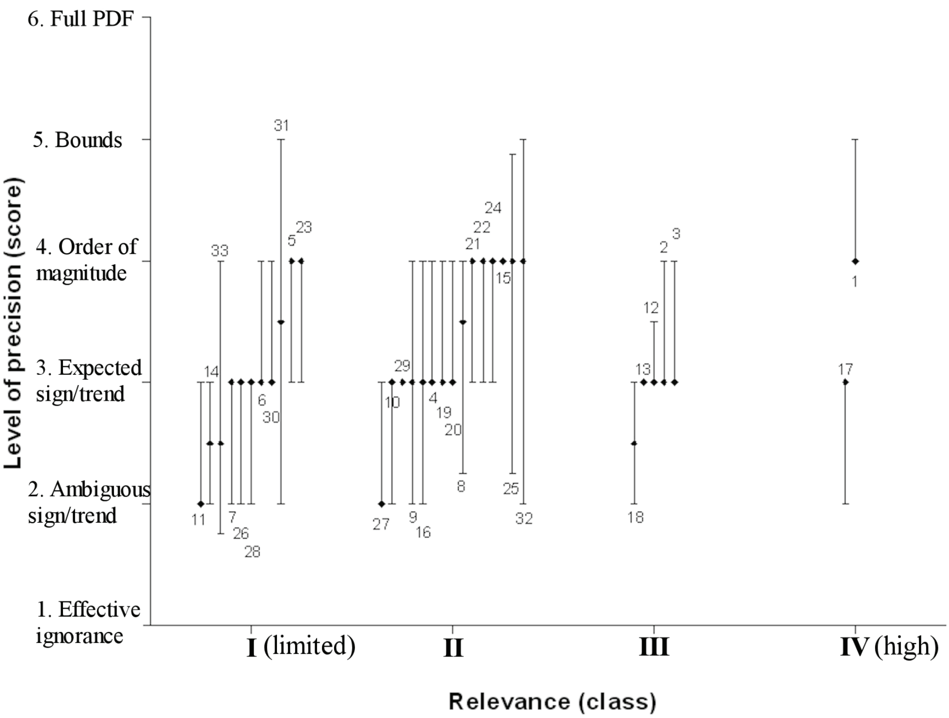

Figure 2.1. Level of Precision (median, interquartile range) of health effects versus relative relevance, ranging from limited (in no one's top-five) to high (often selected). 1-33 refer to Table 2.2.

2.4. Discussion

2.4.1. Reflection on findings

Experts' arguments were generally strong enough to support the interquartile ranges found. Argumentation was more limited for higher/lower scores, for example only referring to "reports" or "opinions". This makes it difficult to verify the tenability of these scores. The depth of argumentation supporting the 75th percentile score for the heat-related effects (5 for mortality, 4 for the other direct effects) seemed relatively limited, referring to literature and experiences with recent heat waves. For flood-related mortality and respiratory problems, the lower scores (2-3 and 2 respectively) received limited argumentation.

Recent Dutch impact assessments provide mostly qualitative information on potential effects of local climate change on health; quantitative information relates to the current and historic state of affairs regarding various health issues (e.g. trends in hay fever prevalence). Data seems most advanced for temperature-related mortality, for which scenario-projections exist. Huynen (2008) calls these "order-of-magnitude estimates", which corresponds with our results. For other high-scoring effects, no quantitative estimates have been found. At the international level, McMichael et al. (2004) provide projections for malnutrition, diarrhoea, malaria, floods/landslides (mortality), and temperature-related mortality. Significant caveats are presented for all. IPCC (2007) additionally discusses modelling studies on other vector-borne diseases (dengue, Lyme, tick-borne encephalitis) and air quality. For flooding, temperature, and air quality, this corresponds with this study. Malnutrition was not included. The studies on vector-borne diseases mostly assess climate suitability and population-at-risk. This seems insufficient to assess health risks for the Netherlands. Menne and Ebi (2006) include a temperature-Salmonellosis relation and season-Campylobacteriosis time-series for the Netherlands. Participants disagreed whether such relations can be used for climate impact assessment, considering the many other factors at play.

The 'Level of Precision' question was relatively broad. Potentially, some participants could have scored effects assuming standard climate projections (e.g. Dutch KNMI'06 or global IPCC scenarios), while others could have taken broader ignorance regarding local climatic changes into account. Because the argumentation focused almost exclusively on uncertainties in assessing health impacts (i.e. translating a climatic change into its health impacts), rather than climatic uncertainties, we interpreted the scores as 'given some climate scenario'.

Score 'ambiguous sign/trend' was often interpreted as 'unclear whether any impact will take place', rather than 'can be positive or negative'. This occurred often when effects were deemed multi-factorial or affected by confounders, or when effects in a wealthy society with well-prepared health and emergency-response systems were deemed unclear. Notable examples include: indirect heat-related effects (e.g. exposure to contaminants), asthma, allergic eczema, and indirect effects of flooding (e.g. infectious diseases). This implies a different level of uncertainty than cases where effects were deemed ‘plausible, but unknown and likely not unidirectional’. Vector-borne diseases and wasps are examples of the latter.

Scores by generalists and subject-matter experts corresponded fairly well. Weighting resulted in minor changes (¼-¾) of interquartiles. Medians were affected in a few cases: +½ for flood-related mortality, air quality-related, and UV-related effects. Regarding air quality and flood-related mortality, subject-matter experts scored notably higher than generalists.

Being based on expert elicitation, results should be treated with some care. The sample of participants is always a limited subset of the total expert-population and situational factors influence the composition of the panel (e.g., who is well-known in the field, who has time to participate). Therefore, results are not necessarily representative. Rather, they give an approximation, and the lines of reasoning behind the scores provide valuable insights into the issue studied. Given the broad coverage of relevant subfields, relative consistency in scores and arguments for most health effects, and consistency with the literature, we consider the findings robust enough to support the general conclusions.

2.4.2. Relevance for other countries.

Many arguments put forth by participants apply to the wider European and global context, particularly when relating to knowledge gaps and complex multi-factorial relations. The level of precision may differ slightly between countries. Respondents noted in several instances that data was available for other countries, but not for the Netherlands. Specific topics may have been studied in some countries, but not in others: e.g. uncommon events (floods, epidemics), and health effects that are currently particularly important in some countries/regions, but not in others. Similarly, respondents noted that e.g. indirect effects of temperature and flooding were less predictable due to highly developed health care and emergency-response systems. In countries where these systems are weaker, data is available from present-day impacts, resulting to higher levels of precision. Conversely, however, for effects for which effective short-term abatement options exist (e.g. shortages of drinking water), such well-developed systems and available resources could constrain impact-estimates. The geographical level of analysis may also be a relevant factor for determining whether quantification is possible.

2.4.3. Policy implications

The level of uncertainty and relevance of health risks have implications for the suitability of an adaptation strategy and the various policy measures (Dessai and Van der Sluijs, 2007). For highly-relevant effects that are well-characterised quantitatively, it would be easier to find support for highly specific policy options targeting only that particular health risk. Conversely, for poorly-characterised, somewhat-relevant effects, one might seek generic strategies affecting a range of health issues. In this case, preferential options would make societal or economic sense irrespective of actual future climate change, or would build adaptive capacity (including stimulating further knowledge development).

For effects with a relatively high level of precision, it would be possible to employ tailored, prediction-based approaches, such as scenario-based dimensioning of adaptation options. Such approaches require considerable knowledge, but can be easily balanced and evaluated, using e.g. cost-benefit analysis. For effects with a low level of precision, it could be better to focus on options that enhance society's capacity to tolerate disturbances, to cope with changes and surprises, and to adapt. This relates to concepts such as resilience and flexibility. Applying these concepts requires less knowledge, but the effectiveness and efficiency of options is more difficult to evaluate. Many other factors are also relevant for the suitability of various adaptation strategies, including: costs, co-benefits, their encroachment on society, and extensiveness of any interventions required (socio-economic, structural, and political efforts/impacts). See Table 2.3.

The results indicate that there is considerable ignorance regarding the magnitude of health impacts of climate change in the Netherlands. Most have medians of 'expected sign/trend', with interquartile ranges reaching 'bounds' in one case only. Given the present state of knowledge, the scope for predict-and-prevent adaptation approaches (risk/scenario-based dimensioning) seems very limited. For most health effects, system-enhancement approaches, such as resilience, seem more suitable. For 'ambiguous' yet highly-relevant effects, such as non-endemic vector-borne diseases, precautionary and other rigorous/costly options could also be considered. However, for such options, it would be advisable to assess the risks of overinvestment and improve their flexibility. For many health effects, climate change worsens already existing issues; some options would be beneficial regardless of climate change. It would be useful to assess the availability of 'no-regret' options (and the climate/health co-benefits of policy on other policy-issues). Considerable ignorance remains, and surprises are possible even for higher-scoring effects. Several experts noted this for flood-related mortality and warned that 'traditional hard engineering approaches' are very vulnerable to surprise. For quantifiable health effects, it may be useful to combine system-enhancement with approaches such as 'robust decision-making', which entails exploring the ability of adaptation packages to function under a range of plausible futures. However, knowledge gaps on the effectiveness of adaptation options may limit this to a qualitative/semi-quantitative exploration at present.

Table 2.3. Implications of uncertainty and relevance for policy.

Effects are of:	**Low relevance**	**High relevance**
High level of precision	Tailored, prediction-based strategies (e.g. risk approach) are feasible. Focus: low costs/efforts or co-benefits.	Tailored, prediction-based strategies (e.g. risk approach) are feasible. Consider costly and extensive options.
Low level of precision	Enhance system's capability of dealing with changes, uncertainties, and surprises (e.g. resilience approach). Focus: low costs/efforts or co-benefits.	Enhance system's capability of dealing with changes, uncertainties, and surprises (e.g. resilience approach). Consider costly and extensive options (including precautionary). Assess overinvestment risks and flexibility.

2.5. Conclusions

Knowledge regarding health risks of climate change is characterized by large gaps and deep uncertainties. Planned adaptation requires profound understanding of the level of uncertainty of anticipated health effects. This study presents a systematic appraisal of uncertainties regarding climate change-related health risks. Using a six point scale, experts were asked to indicate the level of precision with which health risk estimates can be made, given the present state of knowledge. The study focussed on The Netherlands.

The experts assessed that, for most (potential) health effects, it is possible to indicate its sign of change, but not its magnitude. Individual scores varied, generally between being unable to indicate the direction of change and being able to calculate the rough 'order-of-magnitude' of the impacts. Factors that were often indicated to limit quantification include: limited data (in general and country-specific), the multi-factorial nature of the health issues (many important non-climatic drivers of change), and unknown impacts considering a high-quality health system.

For some effects, rough estimates of the order-of-magnitude were deemed possible: heat- and cold-related mortality, the oak processionary caterpillar, microbial contamination of swimming/recreation water, flood-related mortality and air quality-related effects. For these effects, data and impact assessment models are available. However, the availability of locally-specific data is relatively limited, there are many confounding factors, present-day response-relationships may change, and changes in local climate impacts, such as heat waves, are still difficult to project.

For allergic eczema, flood-related exposure to dangerous substances, wasps, UV-related weakening of the immune system, and epidemics of non-endemic vector-borne diseases it may not be possible to even indicate the direction of change. The latter, however, differs per specific disease: for some, effects are unlikely, for others, unknown. In addition to the difficulties noted above, the cause-effect relations of these effects are often highly complex and impacts are likely multi-directional.

These results suggest that the scope for predict-and-prevent adaptation strategies seems very limited at present. Approaches that focus on enhancing the health system's capability of dealing with changes, uncertainties and surprises (for example by increasing resilience, flexibility, and adaptive capacity) are more suitable. For more quantifiable effects, it may be useful to explore the robustness of policy strategies under a range of plausible outcomes, at least in a qualitative/semi-quantitative way. For ambiguous yet highly relevant effects, precautionary measures could be considered, although the flexibility of these options and the risks of these becoming an overinvestment should be assessed.

Because nature, extent and rate of change and its health impacts are uncertain, understanding the relative level of uncertainty is crucial for choices in adaptation strategies and for possible adjustments if climate change effects occur slower, faster, or just different than expected. Therefore, to reduce climate change-related health risks, flexible, multilevel and dynamic adaptation strategies should be developed.

Acknowledgements

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Supplementary Material for Chapter 2

2.Sup.1. Steps in expert elicitation

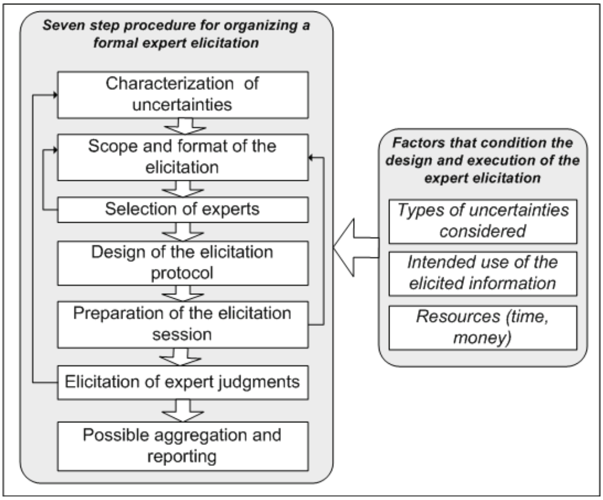

Figure 2.S1. Steps in an expert elicitation. Source: Knol et al. (2010).

2.Sup.2. List of participants

- Neil Adger (University of East Anglia, UK)
- Inez de Boer (The Netherlands Red Cross)
- Ides Boone (Veterinary and Agrochemical Research Centre, Belgium)
- Marieta Braks (National Institute for Public Health and the Environment (RIVM))
- Leendert van Bree (Netherlands Environmental Assessment Agency)
- Bram Bregman (Royal Netherlands Meteorological Institute (KNMI))
- Bert Brunekreef (Institute for Risk Assessment Sciences, Utrecht University)
- Hein Daanen (TNO; e-mail response only)
- Guus de Hollander (Netherlands Environmental Assessment Agency)
- Guy Hendrickx (Avia-Gis, Belgium)
- Paul Heyman (Queen Astrid Military Hospital, Belgium)
- Maud Huynen (ICIS, Maastricht University)
- Fokke de Jong (Climate changes Spatial Planning; Alterra)
- Loïc Josseran (Institut de Veille Sanitaire, France)
- W.F. Passchier (Department of Health Risk Analysis & Toxicology, Maastricht University)
- J. Schols (Department of General Practice, Maastricht University)
- Aad Sedee (Alterra)
- Tom van Teunenbroek (Ministry of Housing, Spatial Planning and the Environment)
- Arnold van Vliet (Environmental Systems Analysis Group, Wageningen University)
- Arjan Wardekker (Copernicus Institute, Utrecht University)
- Letty de Weger (Leiden University Medical Center)

2.Sup.3. Questionnaire

[page 1]

Expert-survey climate change, uncertainties and human health

When completed, please send this survey to: J.A.Wardekker@uu.nl

This survey aims to gain insight into the uncertainties that play a role in the topic of climate change & health in The Netherlands, into the possible relevance of these uncertainties for Dutch climate change adaptation policy, and into uncertainty-robust adaptation strategies. The survey is intended for scientists and professionals with relevant knowledge on climate change & health and climate change adaptation (in general, or health specifically). We intend to publish the results in a scientific report (in Dutch) and an article for an international peer-reviewed journal (in English).

Some questions are fairly expertise-specific. Please answer only those questions you feel capable of answering. Dutch respondents may answer in Dutch, if they feel uncomfortable answering in English.

The survey will take about 0.5-1 hour to complete, depending on how many questions you answer.

After a few background questions (section I), the survey will focus on:

- Possible **level of precision** for health risk estimates (section II). The best-fitting adaptation strategy depends on the level of uncertainty. This section examines this level of uncertainty for various categories of effects.
- Most **relevant uncertainties** and **uncertainty-robust adaptation strategies** (section III). This section will ask you to zoom in on the top-5 most relevant health risks for adaptation in the Netherlands, to further specify the uncertainties for these, and to describe adaptation strategies that are either robust or vulnerable to the uncertainties.

This study is part of a series of 'case-studies on uncertainty and climate change adaptation', carried out by Utrecht University (Copernicus Institute) and the Netherlands Environmental Assessment Agency. It is a follow-up of a more theoretical 'scoping-study' by Dessai and Van der Sluijs (2007). View the briefing note for more information. Contact: Arjan Wardekker (J.A.Wardekker@uu.nl) or dr. Jeroen van der Sluijs (J.P.vanderSluijs@uu.nl).

[page 2]

I. Introduction

1. What is your name? (for identification and acknowledgement; results will be anonymised)

2. In case you've received the link to this survey via a colleague rather than an e-mail from the research team, please indicate your e-mail address.

3. What would you consider to be your expertise regarding climate change and health? [mark all that apply with 'x']

	Generalist or expert on climate (change) adaptation
	Expert on health and climate (change) adaptation
	Generalist knowledge on climate (change) and health, or one or more topics in this field.
	Expert on temperature-related health effects
	Expert on allergies
	Expert on pests (wasps, oak processionary caterpillar)
	Expert on vector-borne diseases
	Expert on food- and water-borne diseases
	Expert on air quality-related health effects
	Expert on health effects due to flooding and storm
	Expert on UV-related health effects
	Other:

4. What is your professional background? [mark all that apply with 'x']

	Scientist
	Policymaker
	Policy advisor
	Health practitioner (medical professional, GGD/public health services, etc.)
	Other:

5. This study will focus on the Netherlands. As the number of Dutch experts on the topic of 'climate change & health' is limited, we've also invited experts from other countries. Please indicate your background. [mark one that applies with 'x']

	Dutch, and have specific expertise or experience on this topic in the Netherlands
	Dutch, no specific expertise or experience on this topic in the Netherlands
	Non-Dutch, but have specific expertise or experience on this topic in the Netherlands
	Non-Dutch, no specific expertise or experience on this topic in the Netherlands

[page 3]

II. Level of Precision of health risk estimates

In the following sections (per category of effects), you will be asked to indicate the level of precision with which you could estimate the magnitude of each health risk for a number of specific health issues (also take into account interactions between issues), at the present state of knowledge. Assume you would be given some time to review the relevant literature, before you would make the effect estimate.

The level of precision will be rated on a scale based on Risbey & Kandlikar (Climatic Change, 2007). A brief description will be provided on each of the following pages. A full description can be found at:
http://www.chem.uu.nl/nws/www/research/risk/LevelOfPrecisionScale.pdf

This section is divided into nine specific subtopics:
a. temperature
b. allergies
c. pests
d. vector-borne diseases
e. food/water-borne diseases
f. air quality-related
g. flooding/storm
h. UV-related
i. (other)

[page 4-5]

IIa. Temperature-related health effects

In this section, you will be asked to indicate the level of precision for health risk estimates regarding climate change & temperature.

Rating:	Label:	Description:
1	Effective ignorance	Knowledge of the factors that govern this effect is so weak that we are effectively ignorant.
2	Ambiguous sign or trend	Some effect is expected, but its sign or trend is not clear. There are plausible arguments either direction (effect could be positive, could be negative; could increase or decrease).
3	Expected sign or trend	It is clear what the sign and trend of the effect will be. However, there is no plausible or reliable information on how strong it will be.
4	Order of magnitude	It is possible to give a rough indication of the magnitude of the effect, a qualitative scoring (e.g. 1-10 scale), or a rough comparison with other effects.

5	Bounds	It is possible to estimate the bounds for the distribution of the effect, e.g. its 5/95 percentiles (effect is only 5% likely to be more than … and only 5% likely to be less than …). However, the shape of the distribution, or best-guess estimates, cannot be provided.
6	Full probability density function	It is possible to provide a full probability density function; the bounds as well as the shape of the distribution.
N/A	Don't know / no answer	

6. Regarding the following specific health issues, with what level of precision would you be able to estimate the magnitude of the health risk for the Netherlands (due to climate change)? Assume you would be given some time to review the relevant literature, before you would make the effect estimate. Use the scale above. [per health issue, mark your rating with ‘x’]

	1	2	3	4	5	6	N/A
Heat-related mortality							
Heat-related cardiovascular problems (Dutch: hart- en vaatziekten)							
Heat-related respiratory problems							
Heat-related stress and sleep disturbance							
Cold-related mortality (decrease)							
Cold-related diseases (e.g. influenza) (decrease)							
Drought-related exposure to contaminants (less dilution of pollutants during extreme droughts)							
Shortage of drinking water							
Dehydration							

Please provide a brief argumentation for your rating above (if any), and if possible, provide some literature references in support.

7. Argumentation and references for 'heat-related mortality':

8. Argumentation and references for 'heat-related cardiovascular problems':

[REPEAT Q7 FOR ALL OTHER HEALTH EFFECTS UNDER ‘TEMPERATURE’][page 6-13]

[REPEAT ABOVE FOR ALL OTHER HEALTH THEMES:]

Allergies:

- Asthma
- Allergic eczema

- Hay fever: duration of pollen season
- Hay fever: (changes in) pollen types, abundance and allergenicity (e.g. invasive species such as ambrosia, CO2 fertilization, plant stress)

Pests:
- Wasps
- Oak processionary caterpillar (Dutch: eikenprocessierups)

Vector-borne diseases:
- Native vector-borne diseases (e.g. Lyme's disease)
- Incidents of presently non-native diseases (e.g. malaria, West Nile virus, tick-borne encephalitis)
- Possible epidemics of presently non-native diseases (e.g. dengue)

Food- and waterborne diseases:
- Food poisoning (e.g. Salmonella, shellfish poisoning)
- Legionnaires Disease (Dutch: veteranenziekte)
- Contamination of swimming/recreation water (e.g. cyanobacteria (Dutch: blauwalg), Weil's disease, Naegleria fowleri)

Air quality-related effects:
- Respiratory problems due to ground-level ozone
- Respiratory problems due to particulate matter (Dutch: fijn stof)
- Air quality-related cardiovascular problems (Dutch: hart- en vaatziekten)

Flooding and storm:
- Flood-related mortality (e.g. drowning, injury)
- Flood-related infectious diseases (e.g. due to reduced water quality)
- Flood-related exposure to dangerous substances and contaminants
- Flood-related respiratory problems (e.g. due to exposure to fungal spores (Dutch: schimmelsporen) in moistly homes)
- Flood-related mental health problems (e.g. psychological trauma)
- Storm-related mortality and injury

UV-related:
- Cataract (Dutch: oogstaar)
- Skin cancer
- Weakening of the immune system

[page 14]

IIg. Other

47. Are there any other important health issues for the Netherlands (due to climate change) that were not included in the questions above? If so, please indicate these effects plus their level of precision for health risk estimates.

[page 15-17]

III. Key uncertainties

In the following questions, you will be asked to zoom in on the top five most relevant health effects (of climate change) for climate change adaptation in the Netherlands in view of public health and to examine the uncertainties more closely.

In estimating what health effects are most 'relevant' for Dutch climate change adaptation, take into account the possible magnitude of the health impact, economic impact, public and political perception, and the availability of options for adaptation and control.

Shortlist of health issues:

1. Temperature: Heat-related mortality
2. Temperature: Heat-related cardiovascular problems
3. Temperature: Heat-related respiratory problems
4. Temperature: Heat-related stress and sleep disturbance
5. Temperature: Cold-related mortality
6. Temperature: Cold-related diseases
7. Temperature: Drought-related exposure to contaminants
8. Temperature: Shortages of drinking water
9. Temperature: Dehydration
10. Allergies: Asthma
11. Allergies: Allergic eczema
12. Allergies: Hay fever: duration of pollen season
13. Allergies: Hay fever: pollen types, abundance and allergenicity
14. Pests: Wasps
15. Pests: Oak processionary caterpillar
16. Vector-borne: Native vector-borne diseases
17. Vector-borne: Incidents of non-native vector-borne diseases
18. Vector-borne: Epidemics of non-native vector-borne diseases
19. Food/water-borne: Food poisoning
20. Food/water-borne: Legionnaires Disease
21. Food/water-borne: Contamination of swimming/recreation water
22. Air quality: Respiratory problems due to ground-level ozone
23. Air quality: Respiratory problems due to particulate matter
24. Air quality: Air quality-related cardiovascular problems
25. Flood/storm: Flood-related mortality
26. Flood/storm: Flood-related infectious diseases
27. Flood/storm: Flood-related exposure to dangerous substances and contaminants
28. Flood/storm: Flood-related respiratory problems
29. Flood/storm: Flood-related mental health problems
30. Flood/storm: Storm-related mortality and injury
31. UV: Cataract
32. UV: Skin cancer
33. UV: Weakening of the immune system
34. OTHER (indicate in question)

48. **Most relevant effect**: [indicate the number from the list above]

49. What makes this effect relevant for the Netherlands (brief description or keywords suffices)?

50. Please describe the key uncertainties that play a role in estimating the magnitude of this health risk. If possible, indicate relevant literature references.

51. Could you describe which adaptation options/strategies would be particularly well-capable of dealing with these uncertainties and which would be very vulnerable to them (and why?)?

[REPEAT ABOVE FOR 2ND, 3RD, 4TH, AND 5TH MOST RELEVANT HEALTH EFFECTS]

If there is anything else you would like to add, suggest or clarify regarding climate change, health, adaptation and uncertainties, you can do so in the field below.

68. Any other things you would like to add, suggest or clarify?

[END OF SURVEY]

2.Sup.4. Relevance of health effects for adaptation policy

Respondents were asked to indicate and rank the five health effects they considered most 'relevant' for Dutch climate adaptation policy in view of public health. They were asked to interpret this in a broad way (allowing for multiple lines of reasoning), taking into account the possible magnitude of the health impact, economic impact, public and political perception, and the availability of options for adaptation and control. Respondents' arguments (practically all by adaptation, policy and health theme experts) are discussed below.

A broad spectrum of health effects was selected as 'most relevant for climate change adaptation in the Netherlands in view of health'. See Table 2.S1 and Figure 2.S2. Heat-related mortality is by far the most often selected effect. Incidents of non-endemic vector-borne diseases is a second high-scoring effect. Other effects that score relatively high include: epidemics of non-endemic vector-borne diseases, hay fever (duration of pollen season and pollen types/abundance/allergenicity), heat-related cardiovascular and respiratory problems, endemic vector-borne diseases, and flood-related mortality. In general, it is notable that the (sub)themes 'temperature: heat-related' and 'vector-borne diseases' were judged to be the most relevant themes for climate change adaptation in the health sector in the Netherlands. The scoring exercise was completed by 16 respondents, plus one who prioritised the health themes rather than the specific effects (on the argument that health impacts of various themes gained relevance due to the combination of specific effects)[9]. He also suggested that respondents would likely indicate their own field(s) of study/work as most important. Scores were cross-checked for this possible bias, but it did not appear to be prominent (scorings in 2 cases seemed clearly correlated with the expert's field, another possibly).

Table 2.S1. Relevance of health effects for Dutch climate adaptation policy. Column 'relevance' indicates the number of times an effect has been selected as 1st, 2nd, etc. most important. 'Points' indicates the point total, where every score of 1st is 5 points, 2nd is 4 points, etc.

Effect:		Relevance					Points:
		1	2	3	4	5	
1	Temperature: Heat-related mortality	6	2	1			41
2	Temperature: Heat-related cardiovascular problems	1		2			11
3	Temperature: Heat-related respiratory problems	1	1		1		11
4	Temperature: Heat-related stress and sleep disturbance	1					5
5	Temperature: Cold-related mortality						
6	Temperature: Cold-related diseases						
7	Temperature: Drought-related exposure to contaminants						
8	Temperature: Shortages of drinking water					1	1
9	Temperature: Dehydration		2				8

[9] This respondent scored the health themes: 1. allergies, 2. vector-borne, 3. temperature, 4. food/water-borne, 5. pests. These are not included in Table 2.S1.

10	Allergies: Asthma			1		1	4
11	Allergies: Allergic eczema						
12	Allergies: Hay fever: duration of pollen season		2		1	2	12
13	Allergies: Hay fever: pollen types, abundance and allergenicity		2	1			11
14	Pests: Wasps						
15	Pests: Oak processionary caterpillar		1				4
16	Vector-borne: Native vector-borne diseases	1	1			1	10
17	Vector-borne: Incidents of non-native vector-borne diseases	1	2	2	1		21
18	Vector-borne: Epidemics of non-native vector-borne diseases	2			2		14
19	Food/water-borne: Food poisoning				1		2
20	Food/water-borne: Legionnaires Disease					1	1
21	Food/water-borne: Contamination of swimming/recreation water				1	2	4
22	Air quality: Respiratory problems due to ground-level ozone			1	2		7
23	Air quality: Respiratory problems due to particulate matter						
24	Air quality: Air quality-related cardiovascular problems				1	1	3
25	Flood/storm: Flood-related mortality	1		1	1		10
26	Flood/storm: Flood-related infectious diseases						
27	Flood/storm: Flood-related exposure to dangerous substances and contaminants			1			3
28	Flood/storm: Flood-related respiratory problems						
29	Flood/storm: Flood-related mental health problems		1			2	6
30	Flood/storm: Storm-related mortality and injury						
31	UV: Cataract						
32	UV: Skin cancer			2			6
33	UV: Weakening of the immune system						
34	OTHER: societal disruption elsewhere	1					5

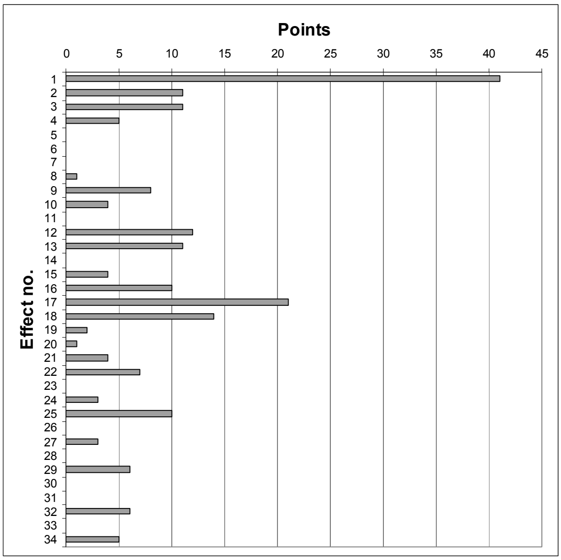

Figure 2.S2. Point totals for relevance of health effects for Dutch climate adaptation policy.

Temperature

A consistent line of argument in respondents' reasoning why *heat-related mortality* is most relevant for adaptation is that homes for the elderly, nursing homes, houses, and city/town planning in the Netherlands are completely not adapted to higher temperatures (and changes in temperatures). A participant makes this argument for Europe as a whole. Other arguments include: political interest, public perception, stress on the health care system, a lack of interest in the topic by the health care sector, and many people are at risk with potentially many victims in a short period of time. One expert notes that the high relevance score applies to the entire topic of heat-related mortality and disease.

For *heat-related cardiovascular and respiratory problems*, respondents note that the effects could be substantial, and refer to many risk factors that could enhance the impact (traffic and city design and related air quality problems, and high incidence of obesity, cardiovascular disease and diabetes).

For *dehydration*, a respondent notes again that homes for the elderly are not adapted. For heat-related stress and sleep disturbance notes that people would be tired during work/school (i.e. resulting in economic impacts).

Allergy

For *asthma*, respondents argue that the number of people already affected is already large, and rising, and is causing a considerable health burden. Changes herein due to climate change would add to this, resulting in high economic impacts (disease prevention, chronic disease treatment). For *hay fever (duration of pollen season)* a similar argument is made: a large number of people will be affected, and it could result in a loss of working days (also an economic impact). For *hay fever (pollen types, abundance, allergenicity)*, it was noted that effects could be substantial and difficult to adapt to.

Vector-borne diseases

For *endemic vector-borne diseases*, a respondent noted that a huge increase in disease risk has been observed in the past fifteen years, and that the costs for treatment of the chronic condition are high, as is the possible disease burden (e.g. due to neurological effects).

For *incidents of non-endemic diseases*, respondents note that effects could be substantial and difficult to adapt to, and that incidents can be difficult to recognise and could result in public unrest. Similarly, for *epidemics of non-endemic diseases*, respondents stress a high potential health and economic impact, the link with public risk perception ('fright factors'), and stress on the health care system.

Food- and water-borne diseases

A respondent notes that the effects of *contamination of swimming/recreation water* could be substantial and difficult to adapt to. Another indicates that it is relevant because of the large amount of water in the Netherlands and recreational habits.

Air quality

On air quality-related health effects, one respondent notes for *respiratory problems due to ground-level ozone* that air pollution is already a considerable health problem and that climate change might add to this. Another indicates for *air quality-related cardiovascular problems* that effects could be substantial and difficult to adapt to.

Flooding and storm

Respondents who consider *flood-related mortality* to be relevant, indicate that flooding is a politically sensitive and culturally important topic for the Netherlands. The risk has a wide spatial extent and large potential impacts (e.g. spatial scale, societal ‘signal value’ of casualties). *Flood-related mental problems* are an underlying stress for populations in hazard areas and an under-recognised issue while effects have been reported even during evacuations (rather than only in case of actual flooding). *Flood-related exposure to dangerous substances and contaminants* could be relevant because there could be widespread exposure and it would be highly politically sensitive due to questions of blame.

UV

UV-related skin cancer could be relevant because of the cultural habits of sun bathing.

2.Sup.5. Uncertainty and options for adaptation

For health effects which respondents considered the most relevant, they were asked to indicate which policy options/strategies they considered to be particularly well-capable of dealing with the uncertainties associated with the effect – and which options/strategies would be very vulnerable to them. The answers will be discussed per health theme. No answers were provided for 'pests'. A total of 34 answers were provided, the majority (28) of which were made by adaptation and health theme experts.

Temperature

Respondents suggested a diverse set of options for *heat-related mortality*, which would be capable of dealing with the uncertainties associated with this health effect. A number of respondents noted information supply and education as important, particularly aimed at vulnerable groups (e.g. the elderly) and other risk groups and caretakers of such groups. In any warning system for heat, responsibilities of relevant actors should be clear and the system should be based on scientific findings regarding risk conditions and options for adaptation. Respondents mention the need for action plans and contingency plans on what to do in case of heat several times. They refer to the Dutch National Heat Plan (VWS, 2007) in several instances. Aside from these 'soft' strategies, physical measures are mentioned as well. Planners could take heat into account in urban/area planning, e.g. by providing parks, open water, wind-corridors, et cetera. These could limit the effects of the urban heat island. Heat could also be (better) taken into consideration in building regulations, design and construction, for instance when developing homes for the elderly. One respondent also suggests further efforts on climate modelling.

Regarding *heat-related cardiovascular and respiratory problems*, several options mentioned above are suggested again; for instance the National Heat Plan and area planning. Other suggestions include monitoring and surveillance, 'early warning', data collection, and development of models for scenario-analysis and impact assessment (i.e. more research). In addition, a respondent notes that limiting/preventing summer smog is important. For dehydration, respondents refer again to the Heat Plan.

Respondents did not suggest any options that were specifically vulnerable to the uncertainties associated with the theme of temperature-related effects.

Allergy

Regarding the theme of allergy, respondents suggested uncertainty-robust options for *asthma* and *hay fever (duration of pollen season, and pollen types, abundance, allergenicity)*. Information supply and warning-systems – and related to this: better timing of medication intake – for hay fever patients are indicated as important by many participants. Furthermore, the allergenicity of the pollen that plants produce should be taken into account when selecting plants for public green spaces and nature management. Monitoring and surveillance, data collection, and development of models is useful as well. Medicine production and increases herein are mentioned as well. Respondents did not suggest any options that were specifically vulnerable to the uncertainties associated with this health theme.

Vector-borne diseases

Limiting the number of tick-bites and quick removal of ticks is important for limiting the consequences of climate change regarding *endemic vector-borne diseases*. Monitoring- and warning-systems are important as well. However, one respondent notes, risk communication and education are not always successful in reducing risky behaviour. Particular risk groups are people participating in outdoor recreation and rangers.

For *incidents of non-endemic vector-borne diseases*, respondents suggest monitoring and surveillance to be important and uncertainty-robust. One respondent notes that education of health professionals on the topic of climate change is useful, as is the creation of flexible and generic action/contingency plans. Another again suggests early warning, data collection and model development. Furthermore, improving general hygiene, production of vaccines and medicines could be enhanced. Conversely, one participant indicates that the creation of large stockpiles of vaccines entails a large risk of overinvestment and is therefore a strategy that is vulnerable to uncertainty. A strategy such as pre-emptive vaccination could also entail the risk of negative health impacts or other side-effects (in addition to overinvestment risk). Action/contingency plans that are very (overly) specific for certain diseases and scenarios/transmission routes would be very vulnerable to surprises.

Regarding *epidemics of non-endemic vector-borne diseases*, respondents note once more that monitoring and surveillance are uncertainty-robust. One respondent also suggests performing literature assessments and surveys on what is happening in other parts of the world regarding vector-borne diseases. Another indicates 'early response' and vaccination as possible options.

Food- and water-borne diseases

Information supply, monitoring/surveillance, early warning and data collection and model development are mentioned as options that are well-capable of dealing with the uncertainties. Other suggestions include good distribution of surface water, keeping in mind the link with urban design, and improving health care in general.

Air-quality

The effects of climate change on health via air quality can be reduced by measures which limit air pollution. Patients with respiratory conditions are a risk group. One respondent mentions once again: monitoring/surveillance, early warning, data collection and model development, keeping in mind the link with urban design, and better health care.

Flooding and storm

Flood-related mortality can be limited by improving water safety in general, via a combination of adaptation approaches that limit the probability and consequences of flooding. Good evacuation and monitoring strategies are also important. The two respondents who comment on this health effect both note that ‘hard engineering’ approaches are very vulnerable to uncertainties. They make risks more unpredictable and increase the vulnerability in case something does happen.

Flood-related mental health problems can be reduced by keeping this issue in mind in disaster response and recovery plans, including in evacuation plans. It is also important to educate and train rescue workers, general practitioners and mental health professionals regarding this health aspect of flooding.

UV

Good information supply is suggested as a strategy that is well-capable of dealing with the uncertainties, for the effects of climate change via ultraviolet radiation.

Other

One respondent suggested that *societal disruption* of societal structures, possibly elsewhere, would have important consequences for health in the Netherlands He noted that present political trends all hamper adaptation and that societal change or transition is needed.

Chapter 3.

Operationalising a resilience approach to adapting an urban delta to uncertain climate changes

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Abstract
Climate change may pose considerable challenges to coastal cities, particularly in low-lying urban deltas. Impacts are, however, associated with substantial uncertainties. This paper studies an uncertainty-robust adaptation strategy: strengthening the resilience of the impacted system. This approach is operationalised for the city of Rotterdam, using literature study, interviews, and a workshop. Potential impacts have been explored using national climate statistics and scenarios and a set of 'wildcards' (imaginable surprises). Sea level rise, particularly in combination with storm surge, and enduring heat and drought are the most relevant potential stresses in the area. These can lead to damage, loss of image, and societal disruption. Unclear responsibilities enhance disruption. 'Resilience principles' made the concept of resilience sufficiently operational for local actors to explore policy options. Useful principles for urban resilience include: homeostasis, omnivory, high flux, flatness, buffering, redundancy, foresight and preparedness/planning, compartmentalisation, and flexible planning/design. A resilience approach makes the system less prone to disturbances, enables quick and flexible responses, and is better capable of dealing with surprises than traditional predictive approaches. Local actors frame resilience as a flexible approach to adaptation that would be more suitable and tailored to local situations than rigid top–down regulations. In addition to a change in policy, it would require a more pro-active mentality among the population.

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3.1. Introduction

The expected impacts of climate change may pose considerable challenges to coastal cities, particularly to those in low-lying deltas (IPCC, 2007b). Changes in sea level, river discharge and weather extremes, combined with increasing potential impacts due to population growth and increasing value of capital, enhance the need to make cities 'climate-proof'. Irrespective of mitigation efforts, some degree of climate change is inevitable, and adaptation will be necessary (Smith et al., 2000; Grübler et al., 2007). Projections of climate change, however, are plagued by substantial uncertainties, particularly when translated into local impacts (Dessai and Van der Sluijs, 2007). For decision makers, it is not always easy or straightforward on how to interpret and use climate scenarios and uncertainty information, and how to appraise the policy implications of uncertainties (Mathijssen et al., 2008; Wardekker et al., 2008a). In literature, various approaches for dealing with uncertainty are formulated for climate change adaptation (Dessai and Van der Sluijs, 2007; Hallegatte, 2009). Examples include: risk approach, anticipating design, resilience, adaptive management, and robust decision making. This paper presents a case-study on a system-oriented strategy: strengthening the resilience of the impacted system to climatic changes.

A central question in this paper is: what could a resilience approach to climate change adaptation entail for an urban delta? The paper aims to operationalise the concept of resilience[10]. This is examined for the municipal areas outside the dike defence zones in Rotterdam, The Netherlands. This flood-prone, densely populated, and economically important region faces numerous climate adaptation challenges. Additionally, major municipal restructuring is planned, which allowed for free exploration of new adaptation concepts, rather than having to work within the limits of an existing situation.

The concept of resilience emerged from ecology in the 1960s and early 1970s (Holling, 1973; Folke, 2006). It has since been adopted by various disciplines and in interdisciplinary work, using diverging definitions ranging from a narrow technical term to an umbrella concept and metaphor (Adger, 2000; Carpenter et al., 2001; Klein et al., 2004; Folke, 2006). Folke (2006) identifies a sequence of resilience concepts, from narrow to broad: (1) engineering resilience, (2) ecosystem resilience and social resilience, and (3) social–ecological resilience. The first two focus on recovery rate and withstanding shock respectively. The last focuses on the interplay between disturbance and reorganization. In the literature on resilience, the concept is currently defined as "the capacity of a system to absorb disturbance and reorganise while undergoing change so as to still retain essentially the same function, structure, identity, and

[10] I.e. from a theoretical concept into a practical framework for generating adaptation options.

feedbacks"(Walker et al., 2004). Three characteristics of (social–ecological) resilience are identified (Carpenter et al., 2001; Resilience Alliance, 2008):

1. The amount of change the system can undergo and still retain the same controls on function and structure.
2. The degree to which the system is capable of self-(re)organization to accommodate external changes.
3. The ability to build and increase the capacity for learning and adaptation[11].

This relatively broad definition seems suitable for the topic of climate change adaptation in urban deltas that face not only disturbing *events* (shocks; e.g. floods), but also disturbing *trends* (e.g. sea level rise). On longer timescales, withstanding and recovering from singular disturbing events is insufficient. A resilient system should also encompass the dynamics to accommodate trends and co-evolve; to 'bounce back in better shape' (Barnett, 2001; Wildavsky, 1998). While umbrella concepts and metaphors are useful inspirational tools, and while using an overly narrow definition could restrict policymakers involved, resilience needs to be made operational to develop policies that increase it. Several studies propose resilience indicators for specific subsystems, aiming to provide a basis for quantitative evaluation of possible policy strategies (e.g. Adger, 2000; Carpenter et al., 2001; Villa and McLeod, 2002; De Bruijn, 2004a,b). Other studies, such as the present paper, qualitatively explore policy options and strategies that could enhance a system's resilience (e.g. Sheltair Group (2003) on urban adaptation strategies in the Greater Vancouver region, Canada). The operational definition of a resilient system used in this study is: "a system that can tolerate disturbances (events and trends) through characteristics or measures that limit their impacts, by reducing or counteracting the damage and disruption, and allow the system to respond, recover, and adapt quickly to such disturbances". In this definition, tolerating disturbances is taken in contrast to resisting these (e.g. by building dikes).

This paper considers a 'resilience approach' a 'bottom–up' way of thinking about adaptation that aims to promote a system's capability of coping with disturbances and surprises, based on the concept of 'resilience'. This is very different from the predict-and-prevent approaches that are traditional in Dutch water management[12]. Similar to the Vancouver study (Sheltair Group, 2003), we assessed trends/impacts, defined characteristics that make a system resilient, and used these to explore options and to specify and categorise how they can contribute to the system's resilience. These

[11] This paper interprets this characteristic as the meta-capacity to build and enhance adaptive capacity. System characteristics such as flexibility, responsiveness and openness towards change and learning facilitate adaptation, making it faster, easier, more efficient/effective, or otherwise more practical.

[12] Prevention-orientation (e.g. prevent flooding and climate change) and promotion-orientation (e.g. promote resilience and sustainability) are psychologically also two fairly different ways to frame goals and behaviour (e.g. De Boer et al., 2009; De Boer, 2010).

characteristics were intended to support ‘resilience-thinking’. The Vancouver study uses a set of ad-hoc ideas on what a resilient urban system implies. This study used six ‘resilience principles’ from ecological and system dynamics literature (Watt and Craig, 1986; Barnett, 2001; Dessai and Van der Sluijs, 2007), and tested their usability for supporting resilience-thinking in relation to urban adaptation:

- Homeostasis: multiple feedback loops counteract disturbances and stabilise the system.
- Omnivory: vulnerability is reduced by diversification of resources and means.
- High flux: a fast rate of movement of resources through the system ensures fast mobilization of these resources to cope with perturbations.
- Flatness: the hierarchical levels relative to the base should not be top-heavy. Overly hierarchical systems with no local formal competence to act are too inflexible and too slow to cope with surprise and to rapidly implement non-standard highly local responses.
- Buffering: essential capacities are over-dimensioned such that critical thresholds in capacities are less likely to be crossed.
- Redundancy: overlapping functions; if one fails, others can take over.

3.2. Research design

The region studied included the municipal areas outside the dike defence zones in Rotterdam, plus the river, surge barrier, connections, and outside service generation (section 3.3). The study consisted of two parts: vulnerability assessment and options generation. Three methods were used: document analysis, interviews (De Jong, 2008), and a highly structured full-day group-elicitation workshop (Wardekker et al., 2008b). For the vulnerability assessment, trends were deduced from literature, but information from local practitioners (interviews/workshop plus local policy documents) was critical in exploring the local implications. Options generation required interactive discussion and was based primarily on the workshop. Interviews and local documents provided information on current plans.

Scientific literature concerning climate change and concerning resilience was reviewed in order to gain an understanding of possible future disturbances due to climate change, and how resilience could play a role in adaptation. Documents concerning the region, its history, development plans, and local policy practices were analysed in order to gain an understanding of the area and the challenges it faces.

Semi-structured interviews were held with five local and regional practitioners to gain additional insight into the area and its policy practices. Respondents included a city planner, housing expert, legal expert, water engineer, and water and water safety advisor from the Rotterdam Department for Urban Planning and Housing (dS+V), Rotterdam Public Works Department (GW), and the Province of South Holland.

The workshop provided a platform for interaction between local practitioners and scientists from a number of relevant disciplines. Participants (eight) included a legal expert, water engineer, landscape architect, and housing expert from the Rotterdam dS+V and GW departments; and a social psychologist, climate scientist, policy scientist, and climate adaptation expert from four Dutch knowledge institutes.

The workshop aimed to construct an overview of relevant disturbances and promising adaptation options. During a process of 'group model building' (Vennix, 1996, 1997), participants developed a system description (conceptual model) of the area. The 'components' of the system (in four categories: physical conditions, usage functions, facilities, and infrastructure) and possible climate-related problems were inventoried. Participants prioritised/evaluated these for inclusion in the group model[13] using basic 1–10 scales, indicating the relative magnitude. Components were scored on (a) estimated essentiality for the system and (b) sensitivity to climate change. The higher a component's weighted average, the higher its priority. For an example, see Figure 3.1. The top five components in each category are listed in Table 3.1. Problems were scored based on estimated importance. Brainstorms were facilitated using a group decision support system with GroupSystems software (Turban and Aronson, 1998; GroupSystems, 2002). The conceptual model was created using Quasta (Van Kouwen, 2007; Van Kouwen et al., 2009). The six principles of resilience were used as in a brainstorm session a framework to generate policy options that can increase resilience of the area.

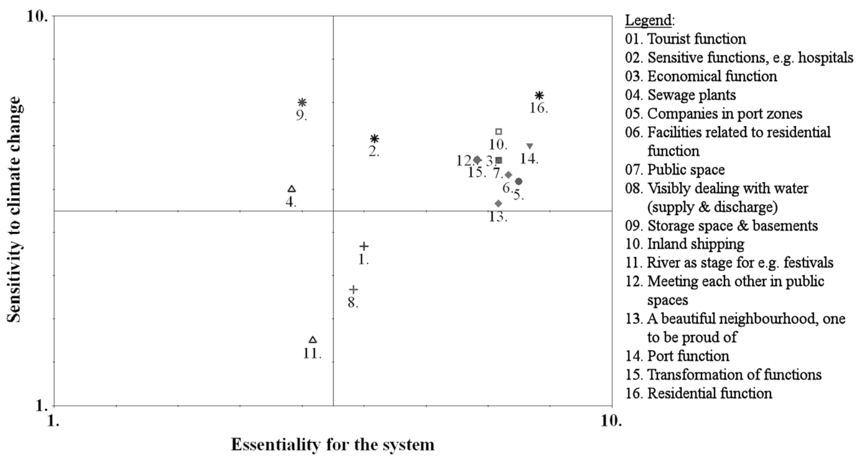

Figure 3.1. Example: participant-scoring of 'usage functions' on essentiality and sensitivity. The further top-right, the higher the priority of taking it into account in further discussion.

[13] This process of collecting individual input and prioritizing/ranking to select the most important ideas is referred to as Nominal Group Technique (Delbecq et al., 1975).

Table 3.1. Critical components of the area (top five per component type, rated by workshop participants based on importance for the area and sensitivity to climate change).

Physical conditions	Usage functions	Facilities[a]	Infrastructure[a]
- Ground subsidence (may be equal to sea level rise) - Water system (water comes from east, west, above, below; sometimes all at once) - Tidal differences - Water barriers (which are an obstacle, both physical and social, towards the hinterland) - Local ecology	- Economical functions (probably mainly services) - Public spaces (green areas, roads) - Inland shipping - Port functions - Residential functions	- (Para)medical facilities - Cooling - Energy supply - Drinking water - Disaster management organisation	- Electricity - Sewage system - Main roads leading in/out of the area - Main water barriers - Maeslantkering storm surge barrier

[a] Note that some things are included in both facilities and infrastructure. E.g. for drinking water supply: availability of drinking water (facility) and pipes (infrastructure). The latter did not make the top-5.

3.3. Description of the area

Rotterdam is adjacent to the North Sea and accommodates Europe's largest seaport. A branch of the river Rhine, the Nieuwe Maas (eastern part) and Nieuwe Waterweg (western part), flows through the city into the North Sea. The study area included the areas outside the dike defence zones in the centre of Rotterdam, about 16 km^2 in size. In addition to this focus area, several other parts of Rotterdam that are critical to the area's functioning were taken into account: the river, downstream Maeslantkering storm surge barrier, connections (e.g. roads and pipes), and outside service generation (e.g. water and electricity).

Even today, the area has a port function, combined with a small scale residential function. The current average ground level of the study area is approximately +3.25 m above NAP[14]. However, some parts have a ground level of approximately +2.50 m NAP and others of +5.00 m NAP. Parts of the area experience limited flooding up to twice per year.

The local government recently decided to redevelop the area. In the ‘city vision’ for 2030 (Rotterdam.dS+V, 2007), the municipality voices the goal “to establish a strong economy and an attractive city”. Partly, this objective should be achieved in the areas outside the dike defence zones, by transforming these into urban residential and working areas. From 2013 onwards, most of the port activities will be translocated to new land extending into the North Sea (the ‘Tweede Maasvlakte’). One part of the old port area, the ‘Waal- and Eemhaven’, will retain its port function and

[14] NAP (Normaal Amsterdams Peil; Amsterdam Ordnance Datum) is the standard Dutch reference height compared to mean local sea level.

was not taken into account in this study. In the remaining part, until 2025, approximately 7000–10,000 houses will be built, as well as offices and other commercial buildings. Foreseen functions for the urban area under redevelopment include: living, working, recreation, cultural functions, and tourism. The area intends to host a wide range of facilities and will include various types of infrastructure (see Table 3.1).

3.4. Climate change related problems for the area

This section will describe the disturbances and policy challenges that the area may come to face due to climate change.

3.4.1. Temperature

The ‘KNMI'06’ climate scenarios for the Netherlands Netherlands (KNMI, 2006; Van den Hurk et al., 2006, 2007) project summer temperature changes of +1.7–5.6 °C in 2100 (compared to 1990). Relevant effects include a likely increase in the number of warm days, more heat waves, and reduced air quality (KNMI, 2006; IPCC, 2007b). Drought during extended warm periods may result in local problems. River water, which is used to cool power plants, may become too warm and in short supply, forcing energy companies to reduce production. Water supply for consumers and companies may be limited, while demand increases. Heat-related health effects would be limited due to the area's open character and close proximity to the river. Warm periods could also be beneficial, providing recreational opportunities for the water-rich area.

3.4.2. Sea level rise

The KNMI'06 scenarios project a local sea level rise of + 0.35–0.85 m in 2100 (KNMI, 2006; Van den Hurk et al., 2006, 2007) excluding ground level subsidence (0.10 m/century). Considering local ground levels (+2.50–5.00 m; +3.25 m average), many parts of the area experience regular flooding (Table 3.2). Projected sea level rise will increase flooding risks. The Maeslantkering closes at a projected water level of +3.00 m (city centre), limiting water levels for the area. Above that level, flooding depends mainly on the Maeslantkering's failure probability (1/100 per order to close; Peijs, 2006; Kwadijk, 2008). Sea level rise would increase closure frequency and could reduce the barrier's effectiveness in limiting city water levels (Rotterdam.GW, 2005).

Table 3.2. Current exceedance frequencies of local water levels in Rotterdam (RWS, 2009).

Frequency (times/year)	Water level (m above NAP)	
	Coast (Hoek van Holland)	**City centre (includes Maeslantkering and its failure probability)**
1/10000	5.05	3.58
1/4000		3.51
1/1000	4.30	3.42 (large majority flooded)
1/100	3.60	3.26 (majority flooded)
1/50	3.40	
1/20	3.15	
1/10	3.00	2.99 (flooding in large parts)
1/5	2.80	
1/2	2.60	2.68
1	2.45	2.56 (flooding in small parts)
2	2.30	
5	2.10	

Local actors perceived sea level rise and flooding as the most prominent issue for the area[15]. Floods could result in damage, societal disruption, and damage to the area's image, reducing its attractiveness for residents and investors. The appearance of not being adequately prepared for climate change may also lead to stigmatisation. Companies may be concerned about the long-term viability of the area for their activities. Other challenges included: spatial claims for future flood prevention, environmental catastrophes in the port areas, traffic disruption due to flooded roads and tunnels, flooded basements and parking garages, and possible plunder during evacuations.

3.4.3. Wind and windstorms

Projected changes in wind speed are relatively small compared to natural interannual variation and long-term fluctuations. The strength of the heaviest storms is also projected to increase slightly. However, projections for extreme wind direction, particularly for northwest (relevant for storm surge), are ambiguous (Van den Hurk et al., 2006). Local wind-related problems are not expected, but storm surge is important for flood risks. Changes in surge level of +0.1–0.25 m are projected due to storminess (1/50 frequency; 2080) (Lowe and Gregory, 2005, Fig. 2). Additionally, port activities may need to be halted during heavy storms.

[15] From a resilience point-of-view, this local framing of the adaptation challenge as a water issue may be a shortcoming; a broader palette of relevant disturbances should be taken into account. In addition, storm surge may be more important for flooding risks than sea level rise.

3.4.4. River discharge

Expected increases in winter precipitation, and upstream rainfall rather than snowfall, can lead to increased peak discharge. This should not be a problem, as local river levels are determined primarily by the sea level (Rotterdam et al., 2005). In combination with sea level rise and storm, it is however relevant for decisions concerning the closing-regime of the Maeslantkering. When this barrier is closed, local river water accumulates. Increased discharge implies that more capacity is needed to temporarily retain river water. Summer discharge is expected to decrease. Low river levels could hamper inland shipping. Water pollutant concentrations and salinisation could increase. Salinisation has consequences for local ecology and drinking water supply.

3.4.5. Precipitation extremes

Precipitation amounts on extremely wet days are projected to increase in the KNMI'06 scenarios. This could result in flooding when the capacity of the sewer system is exceeded. However, this is unlikely as the area is elevated above sea level, with a groundwater level of -1 m, and has many options for drainage.

3.4.6. Societal and governmental issues

The main adaptation-related societal issue was that of unclear responsibilities. Formally, residents who choose to live in areas outside the dike defence zones do so at their own risk; they are assumed to take this risk knowingly and willingly. However, residents perceive the government to be responsible for flood protection, and the exact legal responsibilities for property damage are unclear. Additionally, (new) residents may lack awareness of the risks of living in such an area. They are not actively informed, since no party is responsible for doing so. Furthermore, flood management protocols are absent. Current policies for flood protection in areas outside the dikes are also being changed, and the outcome of this process is unknown. This ‘legal uncertainty’ could make the area less attractive and enhance societal disruption after floods. Unclear responsibilities thus function as a feedback that worsens impacts.

Another issue is the conflicting interests of various policy fields. The area faces many other developments that call for adaptation. For the greater Randstad metropolitan area, urbanisation and housing, economic development, and mobility/accessibility pose significant challenges with uncertain spatial claims (VROM, 2007; Van der Wouden et al., 2008). Uncoordinated communication by various governmental units results in ‘information overload’. Governmental anticipation on changes is slow, and public support for adaptation policy is lacking due to low participation.

3.4.7. Wildcards

A set of area-relevant ‘wildcards’ has been developed[16] to reflect on whether strategies can cope with surprises. They describe events with unknown or low probabilities and possibly large consequences.

1. Rapid ice-sheet melting
Rapid melting will strongly increase sea level rise. The Delta committee (Deltacommissie, 2007) proposes an upper-bound scenario of +0.65–1.30 m in 2100, including subsidence. MNP (2007) posits a worst case of +1.50 m/century.

2. Collapse of the thermohaline circulation (THC)
The implications of a shutdown of the ocean circulation are very uncertain. Relevant potential impacts include: reduced yearly-average temperature, more severe winters, enhanced summer drying, additional local sea level rise, increased cold-related mortality, and negative impacts on summer tourism (e.g. Kuhlbrodt et al., 2009).

3. Frozen port
Changes in atmospheric and ocean circulation may locally offset global warming such that severe winter freezings cannot be excluded. Non-complete freezing would hamper inland shipping. Complete freezing, such as in 1969, could hamper drinking water supply and ice-drift could damage roads and buildings. Low temperatures pose health risks for elderly and homeless. Combination with ‘extreme storm’ and ‘Maeslantkering failure’ could be disastrous.

4. Port malaria incidents
Malaria-infected mosquitoes occasionally board and survive the journey onboard airplanes and, more rarely, ships, and infect people near the airport/seaport (e.g. Isaäcson, 1989). Higher temperatures will increase the number of months suitable for transmission. While the healthcare system is well-capable of dealing with malaria, autochthonous cases are likely to be misdiagnosed. Multiple cases could cause public unrest.

5. Modified German water safety policy
Peak river discharge volumes are limited by the capacity of the German water system. Would German water safety policy become significantly stricter, higher peak discharges may pose new challenges to water management in Rotterdam (although the EU flood directive may limit this potential threat).

[16] The wildcards were included in the handout for use during the workshop's options-brainstorms.

6. Enduring heat and drought
An extended warm period can cause several problems. (a) Low river water tables and warm water may compromise energy production (insufficient cooling capacity) and drinking water supply. Certain areas might need to be disconnected. (b) Sustained exposure to heat may lead to heat stress and higher electricity demand. Health effects are amplified by high humidity and air pollution. (c) Reduced groundwater levels may lead to subsidence and sagging of buildings.

7. Extreme storm
The area has a very open character and is located close to the sea and above sea level. In the eventuality of an extreme storm, it will be relatively exposed to the wind. This may have implications for future spatial planning and building construction.

8. Maeslantkering failure plus extreme storm
Should an extreme (north-western) storm, coincide with the Maeslantkering failing to close, the consequences may be large. The Municipality explored this scenario: with a water level of + 4.10 m most of the area will flood (Rotterdam.GW, 2005).

3.5. Options for resilience

This section describes options that could be considered within a resilience approach to climate change adaptation in the area. It aims to illustrate what such an approach could entail; not to provide a complete list of options. Options are discussed per ‘resilience principle’.

3.5.1. Homeostasis

Homeostasis involves incorporating feedback loops that stabilise the system to external perturbations. One set of options suggested by participants involved removing the feedback-loop of ‘unclear responsibilities’ (paragraph 4.4.6) by establishing clarity on the responsibilities and (financial) liability in case of flooding. Water damage should be insurable and people could be rewarded for accepting occasional or regular water-related problems. New residents should be informed on the risks in the area and the measures they themselves can take to prevent, for instance, flooding. Furthermore, the social structure in the area should be enhanced. Social cohesion could turn the response to disturbances into a more collective effort and increase flexibility.

Early-warning and response mechanisms could limit the impacts of disturbances. Residents should be warned of impending floods, for instance by sending area-wide text messages. Smart flood controls could be activated in case of impending problems and sensors could warn when flood defences may start to fail. Effective disaster management and recovery plans for the area are needed as well. Counter-expertise and -advice should be included in project development to identify possible problems before disruptive events occur.

Urban planning could also contribute to limiting impacts. For instance, the road system could be designed to enhance the removal of water from the area in case of flooding (or ice in case of ice-drift), and to enhance wind flow through the area, providing ventilation. Trees, parks, ‘green rooftops’, and other vegetation could be introduced to enhance cooling. Housing design could also attempt to improve ventilation/cooling. Furthermore, careful selection of construction materials may counteract disturbances (e.g. materials that reduce the urban heat island effect) or enhance recovery (e.g. materials that are easy to repair).

Flexible structures and infrastructure would provide a stabilising feedback as well. Participants mentioned floating and floatable (‘amphibious’) houses, flexible docks, and roads that compensate for inundation. Flexible flood defences (e.g. small scale ‘flood beams’ and large scale flexible storm surge barriers) could be closed when necessary, while not preventing access at other times. Critical facilities, such as the crisis management centre, could be made mobile.

3.5.2. Omnivory

Omnivory involves having several different ways of fulfilling one's needs; when one becomes unavailable, other ways can be used. It is similar to redundancy, but entails multiple different approaches that can be used alongside each other, rather than multiple copies of one approach. The area could diversify energy supply options, for instance by implementing small scale energy generation and energy/heat storage. These options could prevent blackouts should the normal power plants' energy production be reduced during prolonged heat and drought. Options for inland transportation of goods could be diversified. Goods could be transported by rail when inland shipping is hampered by low river levels (due to drought). Conversely, inland shipping[17] could back up rail transport hampered by flooding. These ships should be available in diverse configurations in order to be useful in different situations. Multi-functionality can help as well. For instance, buildings could be designed to be useful for multiple functions. If parts of the area are flooded, functions could easily be relocated to other buildings in other parts of the area.

3.5.3. High flux

High flux allows for quick responses to threats and changes. One way to implement high flux would be to shorten the planning horizon for buildings, and urban planning in general. For instance, one could plan for houses to be replaced after 30 years rather

[17] Shipping is relevant assuming the port function will at least be partly maintained in the future.

than 50; thus ground level can be elevated/modified more quickly. This can be combined with a ‘cradle-to-cradle’ approach and the use of modular elements in buildings; building a “rebuildable city”. If elements of constructions could be reused or deconstructed and later rebuilt, the area could be modified relatively quickly, and at lower costs, to accommodate changing conditions. Other suggestions included: quick notification of high tides, allowing residents and officials to take measures early on (high flux of information), and planning ‘green areas’ and other quickly-modifiable land-uses in areas where future changes may be required (high flux of land use).

3.5.4. Flatness

Flatness involves preventing the system from becoming top-heavy; overly hierarchical. In top-heavy systems, early-warning signals observed at the bottom reach higher levels too slowly due to long or complex/noisy lines. When decision-authority lies at these higher levels, decision-power and reaction-capacity are severely limited. In the context of social–ecological systems, this would involve overly complex procedures for decision making, bureaucracy, and a limited influence of local actors on policy. This would reduce the flexibility, slow the response to disturbances and compromise the adequacy of responses. Options can be divided into two groups. First, the population should be able and be allocated the competence and power to respond to possible problems. It should be made more self-reliant, self-sufficient, self-regulating, and self-organising. The government should leave room and provide capacity for residents to modify the area in order to limit damage and problems. One specific option that was mentioned was to grant neighbourhood directors authority on water safety. Second, policymaking should be made more participative and tailored to the local situation. Workshop participants typified this as “holistic governance” and “creating a clearly communicable safety-culture in which professionals and residents participate”. A separate status for areas outside the dike defence zones might be useful.

3.5.5. Buffering

Buffering entails the ability to absorb disturbances to a certain extent. In the context of flooding hazards, certain (non-essential) low-lying places could be planned to serve as water retention areas for a limited period, until high water tides are reduced. The concept of ‘water squares’ is already used in Rotterdam's water policy plans. Parks, and underground storage areas and car-parks could be used as well. Other areas could be elevated, to house essential functions and to serve as flood refuge. The main roads leading into and out of the area could also be raised. This would allow them to be used during flooding, for instance for evacuations. Lining the road with pegs would indicate the road and allow it to be used during minor flooding.

Another form of buffering is to design buildings with non-essential and/or flooding-resistant functions on ground level. For example, living-quarters and ICT facilities should be moved to higher floors, while ground level could be used for parking. Some facilities (e.g. servers) could be placed outside the area. Water-proofing ground level (e.g. sealable windows/doors) and using materials that are resistant to water, heat, and ice-drift in buildings and infrastructure would help absorb disturbances. Having extra storage capacity and emergency supplies on hand, would help buffer against temporary isolation of the area.

In addition to buffering capacity against disrupting events, one could buffer against disrupting trends by leaving plenty of open spaces (parks, squares, etc.). These could change function relatively rapidly if the future situation would demand this, thus increasing the flexibility of the area's urban planning.

3.5.6. Redundancy

Redundancy involves having multiple instances of something available; when one fails, others can be used. This could involve having multiple routes (roads, ferry services, etc.) into and out of the area. Multiple routes to supply the area with electricity and to remove sewage should also be available. Multiple crisis-centres, in different locations, would be useful should one location become unavailable due to, for instance, flooding. Buildings could have multiple access levels; should the first floor be flooded, people could be evacuated from a higher floor. Vital functions (housing, hospitals, etc.) should have counterparts outside the area as well. These counterparts should be easy to reach and should have the capacity to accommodate a sudden increase in demand.

3.5.7. Other options

During the brainstorm using the resilience principles, participants suggested several options that, in retrospect, did not really fit the principles. One group of options focused on evacuation and refuge during floods. Homes should have evacuation plans, shallow draft boats should be available to evacuate people from the area, emergency exercises should be held regularly, and people should be able to find refuge in buildings as much as possible (reducing dependency on the state of the infrastructure — for example, if the roads were unable to be used as an evacuation route). While these options resemble the ‘high flux’ principle, they entail foresight, planning, and heightened activity when required, whereas high flux entails continuously high dynamics.

Furthermore, some options dealt with planning and management. The area should have clear — and clearly communicated — contingency planning, strategies for managing risks, vulnerabilities, river and water, supplies and storage, et cetera.

Participants suggested segmenting or categorising the area into sub-areas, depending on the vulnerabilities, and tailoring policy options to these sub-areas. Furthermore, the city should examine good practices elsewhere, use the available knowledge-infrastructure, and prevent trial-and-error with citizens.

Several other options focused on a flexible and more positive perception of water issues. These should be seen as a chance to create new ideas, rather than as a threat, and alliances could be made with companies who want to distinguish themselves on this issue.

3.6. Discussion

3.6.1. Reflection on the resilience principles and comparison with the Vancouver study

We used resilience principles derived from ecosystems and system dynamics and applied them as a tool to support creative thinking on adaptation of an urban delta. The principles are grounded in a solid knowledge base regarding how ecosystems behave under stress. However, for urban systems, other characteristics may be relevant (and currently overlooked). These principles need thus to be evaluated in this context of use and should be replaced or supplemented if other principles would better fit this purpose.

All principles proved applicable to urban systems. However, several suggested options had no clear relation to any of the principles used. Options related to ‘positive thinking’ regarding disturbances — thinking with the trends rather than against them — could be described as a type of (perceptional) flexibility in order to stimulate innovative thinking. It seems unlikely that including this as a separate resilience principle would result in a better inventory of adaptation options. Most of the ‘other options’ concerned management/planning and evacuations. This may require an additional principle.

In contrast to our approach, the Vancouver study (Sheltair Group, 2004) used ad-hoc ideas on what a resilient urban system implies. Although it is based on the urban situation, it may overlook relevant system-dynamical elements. A comparison may yield lessons.

The Vancouver study focuses on two characteristics: robustness to stress and adaptability/flexibility in response to changing conditions and objectives. These also feature in the original principles. For instance, buffering relates to robustness and omnivory to flexibility. Literature on adaptation principles suggest a third characteristic, in addition to the two above: increasing the rate of depreciation (Fankhauser et al., 1999) or reducing the irreversible commitment of resources

(Frederick et al., 1997). This relates to high flux. Options can be structural (e.g. physical measures) and non-structural (e.g. modifications to policy/management) (Frederick et al., 1997). However, Vancouver and this study differ in emphasis regarding the resulting policy suggestions: Vancouver emphasises spatial planning and management, while many options in this study are physical and other structural measures.

The Vancouver study notes careful planning, (adaptive) management, foresight and monitoring of local climate change impacts as strategies. As noted above, these appear in this study as well. They are similar, but not equal to high flux. Planning and foresight/research are important instruments of anticipatory adaptation (Fankhauser et al., 1999), which is specific to human rather than natural systems. It is important that information from research/foresight reaches local practitioners (Frederick, 1997; Barnett, 2001). The present principles may overlook options to enhance anticipatory responsiveness. Therefore, we suggest adding ‘foresight, preparedness and planning practices’ as resilience principle.

Related to planning, the Vancouver study interprets ‘adaptability’ as: flexibility (minor shifts in how systems function, space is used), convertibility (changes in use of land or buildings), and expandability (changes in quantity of space for particular uses). These could perhaps be interpreted as a system's structural ‘elbowroom’. In this study, they are covered under omnivory and buffering. However, not all forms of convertibility are omnivory. Relocating existing functions to other spaces/buildings is (multiple locations to fulfil the function), but attracting/switching to new functions is not. As ‘elbowroom’ is highly important for resilience against disturbing trends, it can serve as additional principle. To prevent confusion with ‘adaptive capacity’, we suggest naming it ‘flexible planning/design’.

Finally, the Vancouver study discusses concepts such as compartmentalisation, modularisation, ‘short loops’, and shock-resilient cells. These concern (but are broader than) distributed services and infrastructure (omnivory) and self-sufficiency (flatness). They provide a basis for coordinated response and recovery and can halt “the cascading of problems from one location or system to another” (Sheltair Group, 2003). Compartmentalisation could be added as another principle.

3.6.2. Reflection on the approach and results

Participants considered resilience a useful concept for local climate adaptation and were positive on the way it was operationalised[18]. While the resilience principles seem difficult concepts to grasp, workshop participants had no difficulty working with them.

[18] Some participants did question the usefulness of the group model building exercise; partly due to the limited time available and switching between two software packages. It did however provide useful insights into participants' lines of reasoning regarding impacts. It could be usefully streamlined by developing an initial conceptual model with experts, then having it critiqued by practitioners.

Combined with a short description and practical examples, they were intelligible and facilitated generation of options. The combination of scientists and regional practitioners in the workshop was useful, but (in this case) perhaps not critical because the practitioners were already experienced and knowledgeable on climate impacts. The scientists were important for the process. Particularly, one scientist seeded the group with examples on resilience-based adaptation in other regions, and the social scientists provided focus on the societal effects/implications of impacts.

A drawback of our approach is that it only generates a list of options without offering means to choose among them. Feasibility of the options has not been evaluated. Some options can be considered 'no-regret', such as enhancing interaction with residents and keeping criticality/vulnerability in mind in spatial planning (e.g. hospitals/care-homes on high ground, squares/parks in lower parts). For additional options, several suggestions can be made. Firstly, it is difficult to assess their relative contributions to resilience and to limiting climate impacts in general, preventing cost–benefit analysis and comparison with other adaptation approaches. It may be possible to assess the contribution to individual resilience principles using multiple (semi-)quantitative and qualitative indicators. Secondly, it is important to assess the possible (negative and positive) side-effects of options and strategies (Hallegatte, 2009). For instance, disturbance-proof materials may increase the cost of living in the area, which would have implications for socio-economic policies. They may also reduce the potential for high flux. One should assess which options are complementary and which ones conflict (Fankhauser et al., 1999), among resilience-options as well as between resilience-options and options of other approaches (e.g., raising ground levels (predict-and-prevent) reduces the usefulness of extensive water retention areas (resilience)). Similarly, it is important to assess possible conflicts and synergies with mitigation (e.g. air conditioning (homeostasis) would increase energy consumption). Thirdly, the time horizons of options will need to be considered (cf. Frederick, 1997; Fankhauser, 1999). Some decisions have long time horizons and cannot be easily changed later. An exercise in this study suggested that housing- and port-related functions have long horizons, while commercial and tourism functions have shorter ones. The timing of climate impacts and other developments/trends may also call for certain options to be taken before a certain point. Particularly, decisions with large spatial claims would need to be taken soon, or the limited space may already be claimed for other (long-term) uses. Concluding the above, an assessment of the costs, co-benefits, and tradeoffs of options will be useful for determining the timing, priorities, and level of ambition for resilience-oriented adaptation.

3.6.3. Resilience and climate change adaptation under uncertainty

A resilience approach to a climate change adaptation should be able to limit impacts even if magnitude and direction are uncertain or unknown (Dessai and Van der Sluijs, 2007). Policy-relevant uncertainties can include statistical uncertainties, scenario uncertainties, or recognised ignorance (Walker et al., 2003).

Regarding statistical uncertainties, strategies should be able to deal with a continuous range of conditions, rather than only the 'average'. For instance, they should not only be viable for 'average' temperatures, but also for unusually warm/cold situations. Buffering and homeostasis reduce the impact of disturbances that vary in magnitude, and, depending on their extent, nullify that of more frequent events. When impacts do occur, principles that enhance the responsiveness (e.g. high flux, preparedness/planning) or allow for failure (e.g. omnivory, redundancy) will remain beneficial. Thus, resilient systems can cope with statistical uncertainty.

Scenario uncertainty stems from limited predictability of the future. Scenarios are plausible future developments of a system and/or its driving forces. All principles would limit the effect of disturbances under many scenarios. Some principles however are particularly useful in allowing the system to adjust to the trends. Flatness and high flux would enhance the effectiveness and speed of adaptation. Foresight and preparedness/planning and flexible planning/design further assist in both anticipatory and reactive adaptation to the way the system and disturbances may or will evolve. Thus, resilient systems can cope with scenario uncertainty.

Wildcards ('imaginable surprise scenarios') can be used to assess whether systems can cope with recognised ignorance. They can be divided into three types: (type-1) extreme forms of expected trends, (type-2) opposites of expected trends, and (type-3) completely new issues. Options can be expected to remain beneficial under type-1 wildcards. Under type-2 wildcards, many options will continue to be beneficial. Those that enhance flexibility and responsiveness can be expected to perform quite well. Some options, such as disturbance-proof materials or building-designs, could be no longer beneficial (though not necessarily detrimental) if a disturbance develops in an opposite way. It could be prudent to take the possibility of opposite impacts into account when designing such impact-specific measures. Relatively few options suggested by participants (see section 3.5) would protect against type-3 wildcards, such as port malaria incidents. Monitoring would be helpful against such wildcards. However, in the case of malaria incidents, monitoring may fail due to misdiagnosis, and would not prevent possible public unrest following incidents. Options that could be beneficial include increased interaction between scientists and locals (medical professionals, citizens, officials) and shortening communication chains. This would involve pre-emptive education (e.g. informing general practitioners of the possibility of port malaria incidents), taking into account observations by the local population (including general practitioners) in monitoring programs, contingency planning, and adequate public information supply in the event of incidents. Emerging and unexpected issues should specifically be taken into account. Regular reassessment and updating of existing policies could also be useful to take such new knowledge into account (McCray et al., 2010). Such flatness and foresight and preparedness/planning options would increase resilience against type-3 wildcards. Concluding, resilient systems can cope with recognised ignorance.

3.6.4. Resilience versus other adaptation approaches

Traditionally, Dutch water management focuses on predictive approaches, reducing the probability of occurrence of disturbances (e.g. building/raising dikes), by designing for a desired safety level (e.g. a design flood level of 1/10,000 yr). This probability-oriented risk approach (‘prevention principle’) can cope well with statistical uncertainty (Dessai and Van der Sluijs, 2007), in a cost-efficient manner. Using predictive modelling, one can cope with scenario uncertainty, often by dimensioning to the maximum likely scenario. Potential downsides are the risk of overinvestment, limited flexibility, and increased vulnerability if the projection turns out to be too optimistic. Flexible approaches such as anticipating design can be helpful here. The potential for coping with surprises is very limited. Overdimensioning adaptation measures to cope with type-1 surprises would entail basing policy on an assumed worst-worst case scenario, requiring huge investments and highly invasive measures, and strongly enhancing vulnerability against a failed projection. Such approaches may also fail (no or negative effect) under type-2 surprises. Obviously, predictive approaches do not protect against type-3 surprises at all.

Resilience could therefore complement other approaches, such as robust decision making (Lempert and Groves, 2010) and predict-and-prevent oriented approaches, to arrive at an overall strategy that limits probabilities, impacts, and exposure. For urban deltas this is particularly salient, because the large concentrations of population and capital imply that risks remain high even when probabilities are reduced. This holds even truer for areas where conventional probability-reducing measures (e.g. dikes) are not feasible or desirable, and for disturbances whose probability cannot be controlled through adaptation (e.g. the occurrence of heat waves).

Participants noted that current water safety regulations are rigid and top–down, imposed by national government and regional water boards. However, local institutions and populations have the knowledge of the local conditions that are central to climate-related risks, and need to be enabled to evolve their own response strategies and be granted access to the information and systems that will able them to respond (Moench, 2010). Resilience was framed as an approach that would be more flexible, less regulation-intensive, more focused on ‘growing with the trends’ and better suited to the local circumstances. They considered it a useful approach for local adaptation. It would benefit resilience if local decision makers would receive more room to tailor policies to their own situations. On a lower scale, resilience would be dependent on the self-organization, self-regulation, and self-reliance of the population. It also presents a possibility to increase public participation, potentially increasing support for the adaptation policy. Increasing their responsibilities would demand both suitable formal frameworks and a different mentality among the population, as well as investments in increasing their competence. As participants noted, attitudes such as “the government will solve it for us” and a “claim-culture” (regarding flooding damage) would not be suitable.

3.7. Conclusions

This paper has operationalized ‘resilience’ as an approach to climate change adaptation under uncertainty, by means of a case-study in the areas outside the dike defence zones in Rotterdam, the Netherlands.

Climate change is expected to impact this urban coastal delta in numerous, and often uncertain, ways. Sea level rise is expected to be a major disturbance, particularly if combined with possible changes in storm surge conditions. These can increase the flooding frequencies and risks in these already flood-prone neighbourhoods. Other disturbances include increased temperature and decreased summer river discharge. These could result in problems for electricity supply, drinking water supply, water quality, and air quality. Relevant wildcards for the area include: thermohaline circulation collapse, port freezing events, port malaria incidents, modified German water safety policy, enduring heat and drought, extreme storm, and failure of the Maeslantkering storm surge barrier during an extreme storm. Participants framed the impacts of disturbances as issues of societal disruption, property damage, and attractiveness and image of the area.

Using six *resilience principles*, various options were generated to increase resilience. *Homeostasis* can be enhanced by creating greater clarity on responsibilities, early-warning, response, and feedback mechanisms, spatial planning strategies that reduce impacts or enhance recovery, and flexible structures, infrastructure and flood defences. *Omnivory* can be created by diversifying and distributing electricity generation, diversifying transportation options, and creating multi-functional spaces and buildings. *High flux* can be implemented by reducing planning horizons, possibly combined with cradle-to-cradle approaches, and planning easy-to-modify land-uses in areas that may need quick modification. *Flatness* involves enabling local populations to self-respond to disturbances (self-sufficiency, self-regulation, and self-organization), and increasing public participation in climate adaptation. *Buffering* can be enhanced by creating disturbance-proofed, low-elevation spaces (e.g. squares and parks) and ground-floors, with non-essential functions. These absorb the first impacts of disturbances; essential functions are moved to higher elevations. Leaving plenty of open space would enhance buffer-capacity against future trends. *Redundancy* could be implemented by creating multiple routes for electricity supply and transportation and multiple access levels for buildings, and by duplicating vital functions.

The resilience principles (plus practical examples) succeeded in making resilience sufficiently operational for local actors to translate the concept into concrete options. For urban climate adaptation the original six principles can be supplemented with: (a) foresight, preparedness, and planning (including monitoring, management and contingency plans, evacuation exercises, and specific attention for communication and emerging/unexpected issues), (b) compartmentalisation, and (c) flexible planning/design. Resilience provides a useful approach that is robust to the many uncertainties that decision makers face regarding climate change adaptation, including to surprises, and therefore has added value for climate change adaptation. Local actors framed resilience as a highly flexible approach that is adaptive to both the changing environment and to the local situation and needs. Such flexibility would however require suitable formal frameworks (legal and governmental) and a different, more proactive mentality among the local population.

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Chapter 4.

Ethics and public perception of climate change: Exploring the Christian voices in the US public debate

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Abstract
Climate change raises many questions with strong moral and ethical dimensions that are important to address in climate-policy formation and international negotiations. Particularly in the United States, the public discussion of these dimensions is strongly influenced by religious groups and leaders. Over the past few years, many religious groups have taken positions on climate change, highlighting its ethical dimensions. This paper aims to explore these ethical dimensions in the US public debate in relation to public support for climate policies. It analyzes in particular the Christian voices in the US public debate on climate change by typifying the various discourses. Three narratives emerge from this analysis: ‘conservational stewardship’ (conserving the ‘garden of God’ as it was created), ‘developmental stewardship’ (turning the wilderness into a garden as it should become) and ‘developmental preservation’ (God's creation is good and changing; progress and preservation should be combined). The different narratives address fundamental ethical questions, dealing with stewardship and social justice, and they provide proxies for public perception of climate change in the US. Policy strategies that pay careful attention to the effects of climate change and climate policy on the poor – in developing nations and the US itself – may find support among the US population. Religious framings of climate change resonate with the electorates of both progressive and conservative politicians and could serve as bridging devices for bipartisan climate-policy initiatives.

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4.1. Introduction

In the United States, the public discussion of the moral and ethical dimensions of climate change is strongly influenced by religious groups and leaders. In February 2006, for instance, a group of 86 US evangelical leaders, under the auspices of the Evangelical Climate Initiative (ECI), challenged the Bush administration on global warming with their “Evangelical Call to Action” (ECI, 2006). The document states that climate change is an urgent issue that will impact the poor most of all, and calls for stringent emission controls. Other religious groups and leaders, in the US and other countries, have taken similar positions (Wardekker and Petersen, 2008). The (religious-)ethical aspects of climate change are the central theme of their statements. The debate has attracted considerable attention in the media, and some mention in scientific forums as well (e.g. Nisbet, 2006; Kolmes and Butkus, 2007; Nisbet and Mooney, 2007). Also theologians increasingly reflect on the (religious) challenge of climate change (e.g. McFague, 2008).

Simultaneously, climate change and climate policy have become more prominent in the US political debate, often with moral and religious-ethical[19] connotations. For example, Al Gore notes in his “An Inconvenient Truth” that it is “deeply unethical” to allow the rise in CO_2 emissions to continue (Gore, 2006). The book adds specifically religious discourse to the movie’s general ethical discourse, as does Gore’s Nobel Peace Prize lecture, where he compares the Intergovernmental Panel on Climate Change’s ‘Fourth Assessment Report’ to a quote from Deuteronomy presenting a choice between life and death (“Therefore, choose life”) (Gore, 2007). In the State of the Union of January 2007, President Bush referred to climate change for the first time as a serious societal issue, noting that technological breakthroughs would allow us to become “better stewards of the environment” (Bush, 2007). And in his presidential campaign, Barack Obama wrote: “My values speak to . . . the expanse of God’s creation that is warming day by day” (Obama, 2008). Religiously inspired discourse seems to play an important role in the US public debate on climate change.

This paper analyzes the religious voices in the US public debate on climate change in order to typify the various discourses, focusing primarily on the discourse among Christian groups. Jewish groups have been taken into account to a lesser extent. Christian (and Jewish) traditions play an important role in American public and political life, and in the American societal and cultural debate (cf. Hunter, 1991; Guth et al., 1995; Layman, 1997; Habermas, 2006; Lindsay, 2007). This influence may take the form of, for instance, party identification, electoral choices, political cues in

[19] The terms ‘moral’ and ‘ethical’ are often used synonymously, while others make a distinction for varying reasons and in different ways. This paper will not attempt to expressly segregate the terms, as no distinctions are made within the sources studied.

preaching, lobbying and activism, and public perception of specific issues. Christian groups have often spoken out on issues that have moral dimensions, and apparently they consider the environment and climate change to have such dimensions as well. Our interest in studying Christian voices in the US public debate is to gain empirical access to how an important segment of the US population perceives climate change and what are considered as the relevant ethical dimensions of climate change. The public voices from Christian groups can be considered as proxies for the views supported by the larger communities.

As should be expected, there is a large diversity of views on the climate change issue both within and among Christian denominations. In the US context, particularly the voice of evangelical leaders is considered to be quite influential among Republicans. A plea for strict climate policy by such leaders may seem remarkable. Evangelicals are thought of as politically conservative, and there appears to be a strong distrust and alienation among evangelicals towards environmentalism and environmental concerns. They link these to liberalism, 'new age'-like ideas and nature worship (cf. Sirico, 1997; Harden, 2005; Ekklesia, 2006; Hagerty, 2006; EEN, 2007; Ford, 2008). Interestingly, religious sources that plea for strict environmental policies often reframe the topic to 'creation care' or 'environmental/climate stewardship', avoiding such connotations (Harden, 2005; The Economist, 2007c). Some groups specifically present themselves as religiously or politically conservative. Regarding Christian traditions in general, some have argued that the classic 'dominion' argument (mankind transcends and has rightful mastery over nature) and anthropocentrism enhance abuse and destruction of nature (e.g. White, 1967; Greeley, 1993; Guth et al., 1995; Schultz et al., 2000; Trevors and Saier, 2006). Others have pointed to 'End Times thinking' (dispensationalism) as an additional barrier to support for environmental policy (Guth et al., 1995).

However, to directly relate religious beliefs to environmental attitudes seems too simplistic. Greeley (1993) and Schultz et al. (2000) argue that, while studies have found a negative relation between Christian beliefs and pro-environmental attitudes, this relation is often small and may be due to political and moral conservatism rather than religion itself. Nonetheless, different religious views do seem to be related to *what type* of concerns people hold. For example, Schultz et al. (2000) found that respondents expressing more literal beliefs in the Bible scored lower on ecocentric environmental concerns, but higher on anthropocentric environmental concerns. Such different bases for environmental concerns could result in different views on the nature of an environmental problem, as well as on the desirability of various policy strategies to counter it.

Climate change is an interesting issue in this respect, as it can be framed (cf. Nisbet and Mooney, 2007) not only as an environmental problem, but also as a development problem. Illustratively, the main motivation in the evangelical "Call to

Action" is the impact of climate change on the poor, particularly in developing countries. This developmental frame has strong *human*-ethical connotations. It involves issues of distributive justice; how equitable is the distribution of costs (e.g. climate-change impacts) and benefits (e.g. economic growth) of emissions, and who is responsible for the problem and for taking policy action (Jamieson, 1992; Grubb, 1995; Brown et al., 2006a; Gardiner, 2004, 2006; Singer, 2006)? For instance, Grubb (1995), Gardiner (2004), and Groenenberg and Van der Sluijs (2005) provide extensive discussions of the ethical aspects of various approaches to assigning emission-reduction targets. Other ethical issues regarding climate change include: responsibility for damages, cost to national economies, procedural justice (who may participate in policymaking and how?), dealing with uncertainties (who should bear the burden of proof? should we act despite remaining uncertainties; when and how?), atmospheric targets, independent responsibilities to act, specific research approaches (e.g. cost-benefit analysis/discounting), and policy strategies and new technologies (e.g. geoengineering) (Jamieson, 1996; Brown et al., 2006a,b; Singer, 2006; Toman, 2006; Gardiner, 2007).

Complex and uncertain issues such as climate change raise many questions with strong moral and ethical dimensions that are important to address in climate-policy formation and international negotiations (Brown, 2003; Brown et al., 2006a; Gardiner, 2006). Such issues cannot be solved by simply calculating an 'optimal solution'. Rather, they invoke fundamental questions on how we ought to live and how humans should value and relate to each other and non-human nature (cf. Rolston, 2006; Hogue, 2007). Religious groups have been at the forefront of public debate on ethical issues on many occasions, and should be in a good position to evaluate the linkages between environment, climate change, development, and human behaviour. Considering the large influence of religion on public life in the United States and the important ethically-charged choices that will need to be made in the coming years concerning international climate policy, the views of vocal US Christian groups merit further study. This paper explores their perceptions and positions in the US public debate on climate change and climate policy, and why they consider these issues a religious challenge. Following from that, this paper presents some possible implications for policymaking, relevant for the United States as well as actors involved in the global climate debate. In the near term, religious voices seem particularly relevant for assessing the possibilities of bipartisan climate-policy making under the Obama administration.

4.2. Methodology

4.2.1. Approach

Different (social) understandings of the world lead to different social actions: within a particular worldview, some forms of actions become natural whereas others become unthinkable (Jørgensen and Phillips, 2002; Runhaar et al., 2006). This paper analyzes the Christian voices in the US public debate on climate change by means of argumentative discourse analysis (Majone, 1989; Fischer and Forester, 1993; Hajer, 1995, 2005; Jørgensen and Phillips, 2002; Runhaar et al., 2006). Argumentative discourse analysis explores patterns in written or spoken statements and related practices in order to identify the representations of reality that are employed. For Hajer (1995), the 'discourse coalitions' that form around lines of argumentation ('storylines') are meant to represent a particular definition of the environmental problem, on which the decision-making critically depends. In this paper, we combine two frameworks to analyze and typify these storylines or narratives: worldviews, on the one hand, and value mapping and argumentative analysis, on the other hand.

The worldview framework employs a quadrant of four ideal-typical discourses regarding sustainability issues (figure 4.1), developed by the Netherlands Environmental Assessment Agency (MNP, 2005a; De Vries, 2006; Petersen et al., 2006; De Vries and Petersen, 2009)[20]. These worldviews are used as a heuristic framework to organize the various opinions on sustainable development, in order to assess where the discourses are located within this ideal-typical space. This is a type of framing analysis (cf. Gray, 2003; Nisbet and Mooney, 2007), analogous to analyzing 'social control frames' using Cultural Theory (Gray, 2003). This does not imply that discourses are simply labelled with a particular worldview. Individuals and groups often cannot be easily placed within one 'box', and factors other than ideological positions influence expressed policy preferences (Wardekker and Van der Sluijs, 2006d). Rather, discourses are compared to the set of worldviews, and the elements they use from various worldviews are used to structure the debate. The worldviews are used as a soft framework to scan for storylines/narratives in the debate.

Fischer's (1995; Van der Sluijs et al., 2003) 'Value Mapping and Argumentative Analysis' framework is used to segregate and compare the arguments used, and to analyze what things various policy actors agree or disagree on. The framework discerns four levels of possible agreement/disagreement: (1) ideological view, (2) problem setting and goal searching, (3) problem solving, and (4) outcomes and fairness. The ideological view is the deepest level where disagreement can occur and can lead to very different views of whether there is a problem or what it is.

[20] Note that these worldviews are inspired by, but not the same as, the worldviews used in 'Cultural Theory' (e.g., Douglas and Wildavsky, 1983; Dake, 1991; Steg and Sievers, 2000).

Ideological argumentation focuses typically on ideology and alternative societal orders. On the next level, problem setting and goal searching, groups may agree on the existence of a problem, but not on identifying precisely what the problem is, how to formulate it, and what the end goal or solution point should be. On the level of problem solving, groups may agree on the existence of a problem and on policy goals but disagree on the strategies and instruments required to reach the goal. At the fourth level, outcomes and fairness, groups can hold different views on what constitutes fair outcomes. Fairness argumentation focuses typically on public interest, unexpected societal side effects, and distributive justice.

Figure 4.1. Worldviews. ***Source:*** **MNP (2005a), modified after Rob Maas in Wardekker and Van der Sluijs (2006d).**

In this paper, the worldviews will be used to typify the policy narratives and the value mapping and argumentative analysis framework will be used to segregate the arguments within these narratives. The approach chosen here yields a somewhat different type of results as compared to, for instance, Stone's (1989) concept of causal policy stories and Roe's (1989, 1994) approach of narrative analysis. Causal policy stories focus on the problem definition in terms of causal mechanism (empirical) and blame (normative), while our approach is more extensive. In addition to causal theories, it examines different lines of reasoning concerning solutions, as people adhering to the same causal story may come to different conclusions regarding policy options. Additionally, it explicitly discusses the ideological and ethical issues that may underlie a policy controversy, which is of particular importance to this study. Compared to Roe's (1989, 1994) approach of narrative analysis, the present approach examines the arguments[21], where Roe examines the structural differences of narratives. The latter can yield interesting insights in the dynamics and power-aspects of a policy controversy. The approach used in this paper yields insights in the perceptions, arguments, and positions. In the case studied, this information can be more straightforwardly related to the perceptions within the overall Christian community, as well as to the secular debate.

4.2.2 Data collection

The study started with obtaining a 'helicopter view' of the discourse by examining online news coverage on the topic. After this initial assessment, the study was broadened to include materials such as opinion documents, press releases, formal resolutions, informative materials, and 'frequently asked questions' sections on websites of religious groups, speeches, blogs, and additional online newspaper articles. Sources were collected using both internet searches and snowball sampling. Sources were selected based on their accessibility, relevance, and coverage of opinions, religious groups, and topics within the debate. In total, approximately 100 documents have been analyzed. These materials provided a representative sample of the US religious public debate on climate change as it is currently taking place in the media and on the internet.

4.2.3 Sample

This study focuses primarily on Christian groups, taking into account Jewish groups to a lesser extent. The Jewish sources analyzed presented a discourse that was similar to the Christian discourses on the argumentative level, although differences were apparent in the symbols and language used. These differences are not examined in this paper. Several joint Christian–Jewish opinion documents and coalitions have also been included in the analysis. The Christian (and Jewish) groups are politically the most influential in the United States, as noted in the introduction, and therefore their views are relevant for formulating climate policy. Additionally, it became apparent during data gathering that these groups are also the most vocal and visible in the US public debate. Internationally, other religions and beliefs, such as Islam and Buddhism, seem

[21] The study assesses what the arguments are, not their scientific validity.

fairly active on the topic[22]. In the US however, opinion material from other religions was found relatively scarce. A considerable amount of analyzable opinion material was available for US Christian discourse, allowing for data triangulation and better coverage of the spread of opinions and arguments. Therefore, the decision was made to limit the study to these groups. Analyzed documents originated from religious groups/churches, associations and umbrella organizations of such groups, religious environmental groups and platforms, and individual leaders. Denominations covered (as self-identified by the sources) include: interfaith (joint Christian & Jewish), interfaith/ecumenical (multiple Christian dominations), Jewish (generic), Reform Jewish, Orthodox Jewish, Evangelical (generic), Catholic, Baptist, Presbyterian, Episcopal, Methodist, Unitarian Universalist, Quaker, Evangelical Lutheran, Reformed, Church of the Brethren, United Church of Christ, and Salvation Army. Denominations that could be identified among signatories of public statements/calls and participation in organizations that made such statements also included: Pentecostal, Orthodox, Mennonite, Church of the Nazarene, and Swedenborgian. For a complete list of organizations and people that were included in the analysis the reader is referred to the supplementary material.

4.3. Christian religious discourses in the climate debate

In the material studied, religious groups presented cases in favour, or against, stricter policies on global warming from a variety of standpoints, using a variety of arguments. These arguments span all four of the worldviews summarized in figure 1. Aside from more generic reasoning on the suitability and acceptability of various policy strategies, several points emerge in relation to these worldviews. Religious discourse which fits in the ‘Safe Region’ worldview typically emphasizes mankind’s right to use the earth, which was granted as a gift to mankind. Discourse related to the ‘Global Market’ worldview focuses on mankind’s duty to develop itself and creation. ‘Global Solidarity’-related discourse deals with the commandment to care for one’s neighbour. And discourse related to the ‘Caring Region’ worldview focuses on values such as moderation and humility (mankind as being only a small part of creation). However, the vast majority of opinion documents do not express only a single worldview. Instead, they express viewpoints and arguments from several worldviews.

Within the diverse body of Christian opinions on climate change, three discourse coalitions – henceforth called ‘religious discourses’ – can be discerned (i.e. these are constructed in, and are a result of, the analysis). Each is related to two of the

[22] For overviews on various religions’ perspectives, see e.g. Climate Institute (2006) on climate change specifically and FORE (2004) on ecology in general.

worldviews used in this study (table 4.1). Religiously inspired opponents of strict climate policy express views that could be described as ‘*developmental stewardship*’. Proponents of strict climate policy express views of ‘conservational stewardship’ and ‘developmental preservation’. *Conservational stewardship* opposes developmental stewardship in the worldview graph (figure 4.1). *Developmental conservation* expresses many of the same values and beliefs as conservational stewardship, but with the important difference that it expresses a more positive portrayal of mankind. Although not all sources contain sufficient information to be able to categorize them into one of the discourses, for each of the discourses, sources can be discerned that can be wholly categorized under them. It is found that there is no simple relation between denominations and the discourses: a large majority of the denominations represented in our sample feature more than one discourse and many denominations (e.g., evangelical, catholic and Jewish) feature all three discourses. In the remainder of this section, we further typify the three discourses and provide specific examples.

Table 4.1. Constructed Christian religious discourses in the US climate debate.

Discourse	Description	Worldviews
Conservational stewardship	Creation has been created ‘good’. This ‘garden of God’ should be preserved, as it was created, as well as possible. Technology and development are possible threats.	Global Solidarity and Caring Region
Developmental stewardship	We are called to fill and subdue the earth, and turn the wilderness into a garden, as it should become. Technology and development are a necessity for this task.	Global Market and Safe Region
Developmental preservation	Creation is ‘good’ and changing; progress and preservation should be combined. God has granted us the creativity to find solutions. Technology and development can present challenges as well as help us in this task.	Global Market and Global Solidarity

4.3.1. Conservational stewardship

Core values in the conservational stewardship discourse relate to preserving creation, of which mankind is a part, and (related to this) care for the poor. Core beliefs are that climate change, its impacts, and human influence on it are large and temporally close (often: already occurring). Views on the fragility of nature are usually not made explicit, but are a mix of considering nature as fragile and as tolerant within limits. Discourse on mankind is often negative, framing mankind as ‘culprit’. Climate change is seen as a threat to the well-being of creation, including the poor.

Ideological view. Creation has been created ‘good’. This ‘garden of God’ should be preserved, as it was created, as well as possible. The commandment of stewardship entails a “sacred obligation to preserve and protect the earth in all of its majesty, this garden with which we have been entrusted, for those who will follow”

(Stone, 2008). The need to protect nature follows from our interdependence with nature, and an extension of the commandment to love one another as well: “We must see the whole creation as our neighbor.” (ABC, 1991) and “we believe that Jesus Christ came as a brother to all created reality” (Sisters of St. Francis, 2008). Some sources focus on development, overconsumption and wasting of resources as a threat to creation; one author even refers to this as ‘decreation’: “We are engaged in the swift and systematic decreation of the planet we were born onto. And does God look at our actions and pronounce them good? I doubt it.” (McKibben, 1999).

Problem setting and goal searching. Climate change leads to a destruction of habitats, vanishing of species or ecosystems, and decline in biodiversity. These issues concerning the impacts of climate change on nature underlie the call for ‘conservational stewardship’. Many sources address a multitude of threats, for instance: “From the rapid melting of glaciers to the bleaching of coral reefs and from the spread of tropical diseases and invasive species to increasing frequency of extreme weather event of all kinds, we know that a virtual Pandora’s Box of woes and disasters has been released that is sure to change life on earth for generations to come.” (QEW, 2007, preface). When the air “is poisoned and polluted (Isaiah 24:5-6), we and all creatures are harmed” (ABC, 1991). “Like Adam, we have been warned and cannot plead ignorance” (Stone, 2008). Vision and strength are needed.

Problem solving. While change will be difficult, action is urgent, because impacts are already occurring. “The first step is the most difficult. We must begin to look at the issues. In doing this, we acknowledge our faith that much can be done. … Acknowledge the complexity of the issues, and that solutions will be both difficult and partial. Make individual and corporate small steps. One Friend does not drive on the first Friday of the month, nor does she invite people to drive to her. Another is setting up a data base for carpooling.” (Street, 1999). Various options to reduce emissions are available. They range from governmental regulations to community action, technological innovation, adaptation, and behavioural change. The suggested solutions are similar to those suggested by developmental preservation (cf. below). Opinion documents usually present fairly generic ideas, such as ‘increasing energy efficiency’, ‘energy from renewable sources’, and ‘technologies that emit little CO_2’. One source, though, notes that “Any responses to this crises that focus simply on technological solutions are bound to fail” (QEW, 2007, preface). Educational documents aimed at their own community mention more specific options and present ‘tips’ and ‘success stories’ of churches, individuals and companies. Religious communities take an active stance. “In the case of the environment, the church's leadership is absolutely mandatory. There is no other force left in our society that is able to say: Some things are more important than endless economic growth” (McKibben, 1999). National and regional topical networks and church associations organize public campaigns, releasing statements, attracting media attention and developing commercials, and influencing other actors by lobbying. They also organize workshops and prepare and distribute informational and educational materials on climate change and energy saving to local churches, so they can educate themselves and their members. They urge churches and religious leaders to set a good example. Interesting examples include national campaigns to replace congregations' light bulbs with energy efficient ones, such as 'How Many Jews Does It Take to Change a Light Bulb?', and religious green energy suppliers/campaigns, such as 'The Regeneration Project' and 'Interfaith Power and Light'.

Outcomes and fairness. Developed nations should reduce emissions and limit further climate change. Few sources related to conservational stewardship discuss fairness, however. Their position on, for instance, whether (and in what way) developing nations should contribute to limiting climate change is not as clear as in developmental preservation (see below). QEW (2007, article 2) notes that "Simple justice requires industrial nations, and the U.S. in particular, to take the first steps to slow global warming. … Let us begin to remove the plank from our own eye so we can see more clearly how to help our neighbors consider the speck of sawdust in theirs." This seems to imply some responsibility for developing nations in the long run. McKibben (1999) suggests that developed countries should enable developing countries to develop in a sustainable way: "And we need to spread those technologies abroad, with a giant program of international aid and cooperation, so that the developing nations do not follow our energy path."

4.3.2. Developmental stewardship

Core values in the developmental stewardship discourse reflect a human mission to use creation's resources to develop the world, and (related to this) care for the poor. Core beliefs are that climate change, its effects, and human influence on it are limited, and (implicitly, but related) temporally distant. Nature is seen as robust. Discourse on mankind is very positive, framing man as 'co-creator'. Strict climate policy is seen as a threat to development. An important implicit assumption – consistent with their core beliefs – is that climate change will not significantly hamper development.

Ideological view. Mankind's task is to "fill and subdue the earth" and to "turn the wilderness into a garden" (Spencer et al., 2005), referring to a more 'landscaped' view of this garden as compared with the view of conservational stewardship to keep the garden as it was created by God. Mankind is placed above nature and nature's role is to serve mankind. While mankind should take care of nature, "human beings come first in God's created order … And that primacy must be given to human beings and for human betterment. If that means that other parts of nature take a back seat, well then they take a back seat" (Land, 2006). Mankind is viewed as a 'co-creator' and human development and population growth are considered a blessing and mission, rather than a threat. God would not have created nature so fragile that mankind could easily destroy it, and God would not have intended healthy nature and human development to be incompatible: “Just as good engineers build multiple layers of protection into complex buildings and systems, so also the wise Creator has built multiple self-protecting and self-correcting layers into His world” and “The Noahic Covenant implies God’s continuing preservation of the Earth … this ought to make Christians inherently sceptical of claims that this or that human action threatens permanent and catastrophic damage to the Earth” (Spencer et al., 2005).

Problem setting and goal searching. The leaders that present this discourse often display ‘climate sceptical’ views on climate change, arguing that climatic changes will be minor and largely due to natural causes, rather than large and due to human activities (for an overview of ‘sceptical’ climate discourse, see e.g. Antilla, 2005; Sudhakara Reddy and Assenza, 2009). As far as there is a problem, that problem is a lack of development of the poor, not the impacts of climate change. Developed nations are better able to adapt to climatic changes and weather extremes, and have more money to spend on the environment as well. Thus, “it matters little how well we mean, if what we do actually harms those we intend to help.” (ISA, 2007). The problem is typically framed as follows: “Whether or not global warming is largely natural, (1) human efforts to stop it are largely futile; (2) whatever efforts we undertake to stem our small contributions to it would needlessly divert resources from much more beneficial uses; and (3) adaptation strategies for whatever slight warming does occur are much more sensible than costly but futile prevention strategies.” (ISA, 2007).

Problem solving. The best way to cope with climate change, if any occurs at all, is to decrease vulnerability through economic development, adaptation, and technological innovation. “If the aim is to help the poor, what matters from the policy point of view is supporting the development process by which countries acquire greater ability to deal with adverse economic, climatic, and social conditions, regardless of cause.” (Beisner et al., 2006). Richer nations have more resources to devote to improve environmental quality. Therefore sources note that stimulating economic development would be beneficial for the environment as well. Others are more positive on the possibility of non-harmful emission-reduction policies: “Government tax and regulatory policies can foster more rapid emission reductions and air quality improvements by encouraging research and development” and “By exporting advanced technologies, developed nations would help developing countries improve their environmental quality and enable their people to become wealthier, healthier and safer. As a bonus, global greenhouse gas emissions would decline significantly.” (Spencer et al., 2005).

Outcomes and fairness. Drastic steps to prevent/limit further climate change will be very harmful to the poor, both in the US and in developing countries. “The Kyoto climate treaty and other ‘solutions’ would do almost nothing to stabilize greenhouse gases or reduce global warming. However, they would send energy prices soaring. In future cold snaps and heat waves, thousands could die, because heating and air conditioning would become unaffordable for many, especially minorities and the elderly" (Beisner and Lapin, 2004). Opponents of strict climate policy note that they have the same motive for their perspectives: concern for the poor. However, they assert that limiting greenhouse gas emissions would slow economic growth and increase the cost of energy, ultimately resulting in increasing prices for other goods and services, including basic necessities. The wealthy can afford such increased costs, but the poor cannot – the burden would weigh most heavily on them. With respect to developing countries, any call for strict policy "asks the poor to give up or at least postpone their claims to modern technology that is essential for a better future for themselves and their children" (Beisner et al., 2006). This is described as a type of 'eco-imperialism'. "Over two billion Africans, Asians and Latin Americans still do not have electricity, and activists tell them they must be content with wind generators, or little solar panels on their huts because fossil fuel plants would cause global warming, hydroelectric plants would dam up scenic rivers, and nuclear power is simply taboo" (Beisner and Lapin, 2004).

4.3.3. Developmental preservation

The developmental preservation discourse is similar to the conservational stewardship discourse except for that it holds a much more positive view on mankind. It presents a belief in (God-granted) human ingenuity and technological and entrepreneurial capacity to prevent conflicts between development and preservation. Climate policy should not hamper developing countries: the developed countries have the responsibility to take action. Views on the fragility of nature are not always made explicit, but can be described as considering nature as tolerant within limits. The approach this discourse takes to stewardship seems akin to a concept such as 'ecosystem services', although the term itself is not mentioned. As compared with conservational stewardship, developmental preservation seems much more appealing to political conservatives (while both discourses find support among political progressives). The recent evangelical initiatives mainly display this type of discourse.

Ideological view. Creation is 'good' and changing; progress and preservation should be combined. In this discourse, the value of solidarity comes to the fore. For instance, one source states: "Catholic teaching calls us to embrace the common good and the virtue of solidarity. The climate is a clear example of a good we hold in common. God embraces all of humanity: our well-being is tied to every other person. We have an obligation to respond charitably to those in need and seek justice for those without a voice." (CCCC, 2008). There is a strong focus on ingenuity and progress: "Together, the people of the world can, and must, use our God-given gifts to develop innovative strategies to meet the needs of all who currently dwell on this planet without compromising the ability of future generations to meet their own needs." (JCPA, 1997).

Problem setting and goal searching. Climate change has strong negative consequences for particularly the poor, both at home and in developing nations. Impacts of climate change on developing nations are seen as morally unacceptable, for two reasons. Firstly, the developing nations are harmed, and receive the most severe impacts, through a problem that up till now is caused mostly by the developed nations ("do unto others…"). This appeals not only to harming others, but even stronger: to 'the rich' harming 'the poor'. An occasional source adds to this that this harm is done in the process of becoming even richer. "Current North American energy-rich and overly consumptive lifestyles are being subsidized by the poor and by future generations" (RCA, 2008). Secondly, the statements remark that the developing nations are also the most vulnerable, and the least able to adapt to climate change. The United States bears a special responsibility: "Because of the blessings God has bestowed on our nation and the power it possesses, the United States bears a special responsibility in its stewardship of God's creation to shape responses that serve the entire human family." (CCCC, 2008).

Problem solving. Action on climate change is necessary and urgent, and certainly doable if we make the effort. Deadly impacts are already occurring and decisions we make today will fix the emissions for some time, due to the long life-expectancy of technologies. "Climate change is the latest evidence of our failure to exercise proper stewardship, and constitutes a critical opportunity for us to do better (Gen. 1:26-28)" (ECI, 2006). The proposed solutions are similar to those suggested by conservational stewardship. Politicians and companies are called upon to demonstrate vision and leadership on climate change. Those that do so are commended and referred to as examples of good practice. With regard to options for governmental action, recent initiatives point to 'market based cost-effective mechanisms', such as 'cap-and-trade', in particular. Proposals in Congress for cap-and-trade schemes are supported. Such schemes reduce emissions through "a business-friendly cap-and-trade program that would spur investments in energy efficiency and renewable energy, making our U.S. economy more efficient and reducing our dependence on foreign sources of energy" (EEN, 2005). The connection with energy dependence and national security is often made. Technology is seen as an important tool. In fact, "if our country does not invest in the new technologies, we are likely to be left in the technological development dust as other countries cash in on the boom" (Lewis and Carlyle, 2002). Developed countries should assist developing nations in developing in a sustainable way ('authentic development'; USCCB, 2001) and in adapting to climate change. Some sources offer suggestions for people to personally contribute, such as fuel efficient and hybrid cars, efficient appliances and light bulbs, writing letters to politicians and business leaders, and influencing companies through shareholder initiatives. Examples of initiatives set up by religious groups include the "What Would Jesus Drive?" campaign and shareholders initiative "Interfaith Center on Corporate Responsibility".

Outcomes and fairness. Developed nations are responsible for reducing greenhouse gas emissions. "In this situation, the United States has both responsibility and opportunity. With 4% of the world's population, we have contributed 25% of the increased greenhouse gas concentration which causes global warming. Moreover, we uniquely possess technological resources, economic power, and political influence to facilitate solutions" (NRPE, 2004). Climate policy should not inhibit the development of developing nations, as "Developing nations have a right to economic development that can help lift people out of dire poverty" (USCCB, 2001). Thus, "In seeking an appropriate balance between consumption and the equitable use of global resources, we need to make a distinction between the 'luxury emissions' of the rich and the 'survival emissions' of the poor. 'From everyone to whom much has been given, much will be required' (Luke 12:48)" (RCA, 2008). Many sources remark that poverty results in environmental degradation as well. Few sources discuss the consequences of climate policy for the poor in the United States itself. Of course, this could be related to their positive expectations regarding the economic effects of strict climate policy. An occasional source does suggest supporting the poor in their energy expenses, for instance by increasing funds for a Low Income Energy Assistance Program (Lewis and Carlyle, 2002).

4.4. Discussion

The present study analyzes the Christian voices in the US climate-change debate by examining published sources. This section reflects on the findings. Firstly, the similarities and differences among the observed discourses are outlined. Secondly, the timeline is discussed. Thirdly, the ways uncertainties are addressed in the discourses are investigated. Fourthly, it is assessed in what respects the religious voices studied differ from secular voices in the climate-change debate. And fifthly, the specific impact of these religious voices on this societal debate and on political decision-making is discussed.

4.4.1. Comparing the discourses

The three discourses use strikingly similar concepts and images. All three discourses describe God as being the owner of the world, and of nature. They regard mankind as stewards with the task of tending to "God's garden". Mankind should have gratitude for the 'gift of creation' and pass it on to future generations. However, the discourses employ very different interpretations of these concepts and images. For instance, conservational stewardship emphasizes that God created the earth as ‘good’ and mankind should preserve it in its original state. Developmental stewardship, on the contrary, emphasizes that mankind should turn the wilderness into a garden, or a ‘garden city’ – implying a much more cultivated/landscaped image of the garden. The discourses of conservational stewardship and developmental preservation are similar in their views on the problem and the goals. Both are ‘green’ religious discourses. However, important differences can be found in their portrayal of mankind and the relationship between man and nature, and their perspectives on the solutions. Conservational stewardship seems to hold much in common with mainstream environmental concerns, and even with ‘green romanticism’ (cf. Prelli and Winters, 2009). Developmental stewardship holds more in common with ‘sustainable development’ discourses and presents a narrative that seems much more appealing to political conservatives than does conservational stewardship.

Three specific ethical themes are at the forefront of the debate: the effects on nature, the implications for future generations (intergenerational equity), and the implications for the poor. They can be found in all three discourses. The most prominent issue in recent debates is the implications for the poor. It is emphasized in developmental stewardship and developmental preservation. Conservational stewardship particularly emphasizes effects on nature. Regarding implications for the poor, developmental preservation and – albeit to a lesser extent – conservational stewardship are concerned about the impacts of climate change on the poor in developing countries and in the United States itself. Developmental stewardship is more concerned about the effects of climate *policy* on these poor. To some extent, these positions could be explained by whether groups believe that human-induced climate change is real and significant. However, proponents of strict policy also voice concerns regarding the effects of policy on the poor (most strongly in developmental preservation). Keeping the implications of climate policy on the poor in mind seems to be a common issue for all discourses. In addition, at least some sources in developmental stewardship seem to support development- and technology-oriented approaches to mitigation. Finally, assisting the poor in adapting to climate change is supported in all discourses, although few sources emphasize it[23].

[23] The reasons for this limited emphasis on adaptation could be rhetorical; sources aim to urge the US to increase emission-reduction efforts (or argue against these). However, other reasons could play a role as well. The World Council of Churches notes that their current ‘dual focus’ (both mitigation and adaptation) was not obvious: “To work on adaptation had been seen as a weakening of resolve on the possibilities of mitigation and hence a weakening of the WCC’s solidarity with victims” (Robra, 2006). Robra (2006) notes that conceptualizing the transition to a dual focus required collaboration with religious relief and development agencies, and that building these relationships “has not proceeded as quickly nor engaged as many agencies as had been initially hoped.”

4.4.2. Timeline and priority

Climate change seems to have attracted considerable attention in the US Christian communities during the past few years. However, the topic is not new within these communities. Statements on climate change used in this study date back to the 1990s. An early example is a resolution by the American Baptist Churches USA (ABC, 1991). Evangelicals spoke out on environmental protection in general (EEN, 1994). More position and opinion materials appear over the late 1990s and early 2000s. Knickerbocker (1998) already describes climate change as an important part of theological teaching and activism for a growing number of clergy and congregations. What is remarkable regarding the past few years, however, is the emergence of a strong conservative evangelical climate discourse, with the 'Call to Action' in February 2006 (ECI, 2006) as a prominent event. The texts do not indicate a reason for this timing, but it is probably no coincidence that the increased attention arose shortly after Hurricane Katrina (August 2005). Still, Abbasi (2006) notes that religious communities have embraced climate change over varying time frames and that this process "just takes time". It is not surprising that it would take more time among conservative evangelicals. Prelli and Winters (2009) suggest that evangelical support is likely to increase due to an ongoing generational shift. High media coverage on climate change during 2006[24] and onwards (Boykoff, 2007; Boykoff and Mansfield, 2009) may have enhanced the success of this new discourse. And, as noted above, the discourse managed to reframe the topic of climate change in such a way that it is now appealing to religious conservatives.

Survey research indicates that climate change is considered a serious problem among US Christians (Pew Forum, 2006), but the weight relative to other issues is also relevant. A majority supports strict environmental regulations, even if this would cost jobs or result in higher prices (Green, 2004, 2008). In terms of voting priority, however, the environment ranks well below the economy and terrorism, but, for all but white evangelicals, higher than abortion and much higher than gay marriage (Pew Forum, 2004). Nearly half of US Christians report that their clergy address the environment; slightly less than gay marriage and less than abortion, but more than evolution/intelligent design and stem cell research (Pew Forum, 2006).

4.4.3. Discourse on uncertainty

As noted in the introduction, complex and uncertain issues such as climate change raise many ethically charged questions. One of the key questions here is how to deal with uncertainties.

[24] Media coverage in 2006 peaked in March (e.g., US release of An Incovenient Truth) and November (e.g., Stern Review, COP12, mid-term Congressional elections, prominent state-level actions) (Boykoff, 2007).

Most opinion documents that plea for stricter climate policy emphasize certainty, rather than address uncertainty. Statements often start with the claim that there is scientific consensus on human-induced climate change and on its large and negative consequences. Interesting exceptions are groups such as the US Conference of Catholic Bishops (USCCB), which explicitly address uncertainty and connect it to its implications (cf. Wardekker et al., 2008a). Uncertainty is placed in the context of a religious (or religiously inspired) frame: the 'virtue of prudence'. "Prudence is not, as popularly thought, simply a cautious and safe approach to decisions. Rather, it is a thoughtful, deliberate, and reasoned basis for taking or avoiding action to achieve a moral good" (USCCB, 2001). Pope Benedict XVI describes acting prudently as a discursive process: "being committed to making joint decisions after pondering responsibly the road to be taken" (CCCC, 2008).

Opponents of strict policy often emphasize uncertainty, arguing that a sufficient basis for strict policy is absent, while consequences of such policy would be significant. Some sources suggest that it is certain that human-induced, large and negative climatic changes and impacts will not occur. Instead of investing resources to prevent uncertain climate change, many opponents of strict climate policy emphasize the importance of (economic) development. This can be regarded as a 'human development' approach to climate-change adaptation (cf. Dessai and Van der Sluijs, 2007).

To support their claims, both parties refer to scientific reports, institutes, and scientists whom they consider reliable. Occasionally, sources stress the religious background of the latter, for instance, when scientists are claimed to belong to their group. In the recent debate, both groups have also actively formed coalitions with scientists.

4.4.4. Religious versus secular voices

From the analysis of 'religious' discourses in the climate-change debate identified in this paper, we can conclude that, particularly when expressing ideological views, religious imagery is dominant in these discourses. The religious discourses add a deeper dimension to the public debate on climate change, and seem to resonate with large audiences. This is what makes religious discourse powerful and an important object for study in the context of climate-policy analysis.

Still, many of the *arguments* put forward in the religious discourses figure in secular discourses as well: these arguments can be considered as generic (i.e. not specifically religious) ethical arguments. In most of the documents analyzed, it indeed appears difficult to distinguish religious from secular lines of reasoning.

From a deliberative democracy viewpoint, the question thus becomes relevant whether the political arguments put forward in the religious discourses are either *inspired* (considered allowed) or *justified* (considered problematic) by religion (cf. Shields, 2007). From this viewpoint, religious arguments should not be allowed to carry additional force in the (secular) debate that should remain pluralistic. This becomes even more pressing when dealing with absolutist (religious) positions: sometimes such positions are not allowed to enter the discourse, for those who put forth such opinions are not willing to criticize their own positions.

4.4.5. Impact on societal debate and political decision making

While it remains to be seen what effects these religious contributions to the public debate will have on climate policy in the United States, several clues for their potential influence can be found. The recent initiatives are attracting attention in the media and among scientists, corporations, NGOs, et cetera. Furthermore, the initiatives do not stand alone in their calls for stricter climate policy; in fact, the religious initiatives are actively forming coalitions with these other parties. Calls for stricter policy are emerging from many other sectors of society, ranging from state and city governments and national politics to corporations, farmers, and 'security hawks' (The Economist, 2007a,b). Coalitions are formed, including between 'unlikely' partners. For instance, Gunther (2006) reports on joint media campaigns by evangelicals, Fortune 500 companies, and the environmental movement. As such, the religious initiatives should not be seen in isolation, but as part as a larger societal debate on climate change, which has led to domestic pressures on the US government to participate more fully in international climate policy. In particular, religious environmental initiatives seem to be making environmental care more accessible to the conservative side of the political spectrum. Where the conventional environmental movement is strongly distrusted among evangelicals and conservatives, these church-based initiatives have reframed climate change from an environmental issue to a religious one. This new frame is much closer to their perceptions and way of life (cf. Nisbet and Mooney, 2007). In fact, religious environmental initiatives seem to take upon themselves roles similar to those of conventional environmental groups.

Opposition to strict climate policies can also be found among US Christian (and Jewish) groups. While they consider nature valuable, considerably more weight is given to mankind. This makes supporters of this 'developmental stewardship' discourse particularly unsupportive of policy proposals that are perceived to be detrimental to the poor. They may be less opposed to development-oriented proposals.

To conclude, the Christian voices in the US public debate on climate change have added to the societal support for climate policy efforts. Progressive as well as conservative politicians can find support among their electorate for policy proposals aiming to limit climate change. Furthermore, while different worldviews can be distinguished among the Christian groups, common imagery and concerns are present as well. Potentially, these similarities could serve as bridging devices for bipartisan policy initiatives.

4.5. Conclusion

Over the past few years, the issue of climate change has received an increasing amount of attention within religious communities in the United States and in the rest of the world. Recent initiatives have attracted considerable attention in the media. Calls to politics to take more notice of the issue originate from a multitude of religious movements. In the United States, Christian groups play a prominent role. Some Christian opposition to these initiatives exists as well. Several US groups have organized counter-initiatives, criticizing religiously inspired advocacy of strict climate policy.

Within the diverse body of opinions and arguments that various Christian (and Jewish) groups put forth, three narratives (‘religious discourses’) can be discerned: ‘conservational stewardship’, ‘developmental stewardship’, and ‘developmental preservation’. Each of these discourses presents a consistent storyline, using similar concepts, images and motives, but holding different interpretations of these.

Conservational stewardship holds that God created the earth as ‘good’, and that this ‘garden of God’ should be preserved as it was created. Mankind is part of nature and has the sacred task to protect the earth. Climate change threatens creation and is therefore morally unacceptable. Change will be difficult, but it is urgent and each person and company should take small steps towards reaching this common goal. Religious communities take an active role, by setting an example, educating their members and lobbying.

Developmental stewardship places nature in a more serving position to mankind. Rather than preserving creation as it was created, mankind should turn the wilderness *into* a ‘garden’, as it should become. Strict climate policies will inhibit mankind from fulfilling this role, from developing and from reducing its burdens (poverty, disease, malnutrition, etc.). The poor, in the US and in developing countries, would have to bear the heaviest burdens of such policies. Rather, economic and technological development should be promoted, thus enhancing societies’ capability to deal with environmental and other problems.

Developmental preservation considers creation to be ‘good’ and changing. Progress and preservation should be combined, and God has granted mankind the creativity to find solutions. The poor will face the most severe impacts of a problem that the rich have created, while they are the most vulnerable and least able to adapt. Developed nations have the moral duty, as well as the opportunity, to prevent this.

Various options are proposed, ranging from regulations to technology, adaptation and behavioural change. Recent initiatives favour cap-and-trade schemes in particular.

The religious voices in the US public debate on climate change emphasize the moral dimensions of the issue. Three ethical themes are at the forefront of the debate: the effects of human-induced climate change on nature (creation care; environmental/climate stewardship), the implications for future generations (care for one's children; intergenerational equity), and the implications for the poor (environmental justice; interregional equity among other things). Many recent initiatives stress the latter. Observing the religious discourses, a robust policy strategy (regarding support in US Christian communities) would have to pay careful attention to the effects of both climate change and climate policy on the poor in developing countries and the United States itself. Religious groups have added to the basis of societal support for both progressive and conservative politicians and the religious framings of climate change could contribute to bipartisan climate policy efforts.

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Supplementary Material for Chapter 4

4.Sup.1. Organizations included

(formal statements, papers, website commentary, etc.):

American Baptist Churches in the USA
California Interfaith Power and Light
Catholic Coalition on Climate Change
Center for Health and the Global Environment, Harvard Medical School
Central Conference of American Rabbis
Church of the Brethern
Coalition on the Environment and Jewish Life
Cornwall Alliance
Episcopal Church in the United States of America
Episcopal Ecological Network
Evangelical Climate Initiative
Evangelical Environmental Network
Evangelical Lutheran Church in America
Forum on Religion and Ecology (materials from various contributors)
Interfaith Center on Corporate Responsibility
Interfaith Climate Change Network
Interfaith Council for Environmental Stewardship
Interfaith Stewardship Alliance
Jewish Council for Public Affairs
Maine Council of Churches
National Association of Evangelicals
National Religious Partnership for the Environment
Presbyterian Church (U.S.A.)
Quaker Earthcare Witness
Quaker.org
Reformed Church in America
Religious Action Center of Reform Judaism
The Acton Institute for the Study of Religion and Liberty
The Regeneration Project, Interfaith Power and Light
The Sisters of St. Francis of Philadelphia
Toward Tradition
Unitarian Universalist Association of Congregations
United Church of Christ
United Methodist Church
United States Conference of Catholic Bishops
Washington Association of Churches
We Can Solve It campaign
What Would Jesus Drive campaign
World Council of Churches (International)
Yale F&ES Conference on Climate Change (conference's 'religion and ethics' synthesis)

4.Sup.2. People included

(personal opinion pieces, commentary/statements in news articles, etc.):

Anderson, L. (Evangelical)
Ball, J. (Evangelical)
Bassett, W.T. (Salvation Army)
Beisner, E.C. (Evangelical)
Bingham, S. (Episcopal)
Bush, G.W.
Campbell, J.B.
Carlyle, K. (Quaker)
Cizik, R. (Evangelical)
Dobson, J.
Driessen, P.K.
Gore, A.
Green, J.C.
Griffin, M.
Haggard, T. (Evangelical)
Hallman, D.G.
Hedman, L. (Evangelical)
Hinderaker, J.
Hogue, M.S.
Howard, S.
Hunter, J.
Johnson, A. (Evangelical)
Land, R. (Baptist)
Lapin, D. (Orthodox Jewish)
Lewis, S. (Quaker)
Litfin, D. (Evangelical)
McKibben, B. (Methodist)
Obama, B.H.
Patriarch Bartholomew I of Constantinople (Orthodox)
Pope John Paul II (Catholic)
Pope Benedict XVI (Catholic)
Robertson, P. (Baptist)
Robra, M.
Schneider, H.
Sharpton, A. (Baptist)
Sirico, R.A. (Catholic)
Spencer, R.W.
Stone, W.G. (Jewish)
Street, K. (Quaker)
Stults, M.
Van Walsum, P.
Wallis, J. (Evangelical)
Whiteman, K. (United Church of Christ)

Chapter 5.

Uncertainty communication in environmental assessments: Views from the Dutch science-policy interface

Abstract
Scientific assessments of environmental problems, and policy responses to those problems, involve uncertainties of many sorts. Meanwhile, potential impacts of wrong decisions can be far-reaching. This article explores views on uncertainty and uncertainty communication in the Dutch science-policy interface and studies several issues concerning presentation of uncertainty information. Respondents considered uncertainty communication to be important, but it should be concise and policy relevant. Several factors influence policy relevance, including the place of an issue in the policy cycle, and its novelty, topicality and controversiality. Respondents held particular interest in explicit communication on the implications of uncertainty. Related to this, they appreciated information on different sources and types of uncertainty and qualitative aspects of uncertainty (e.g. pedigree charts). The article also studies probability terms, particularly for IPCC's 33–66% probability interval ('about as likely as not'). Several terms worked reasonably well, with a median interpretation of 40–60%. Finally, as various target groups have different information needs and different amounts of attention for various parts of a report or communication process, it is important to progressively disclose uncertainty information throughout the communication. Improved communication of uncertainty information leads to a deeper understanding and increased awareness of the phenomenon of uncertainty and its policy implications.

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5.1. Introduction

Scientific assessments of complex environmental risks, and policy responses to those risks, involve uncertainties of many sorts (Funtowicz and Ravetz, 1990). These uncertainties can be present in various stages of the policy cycle, ranging from the initial detection of a (possible) problem, to policy formulation and, eventually, monitoring and adjustments to existing policies. More research will not necessarily reduce uncertainty and decisions often need to be made before conclusive evidence is available (Risbey et al., 2005; Van der Sluijs, 2005; Van der Sluijs et al., 2005a,b; Wardekker and Van der Sluijs, 2005). Meanwhile, the potential impacts of wrong decisions on, for instance, health, economy, environment and credibility can be huge. Communication of uncertainties aimed at policymakers, as well as other parties involved in policymaking, is important because uncertainties can influence the policy strategy that is selected. Furthermore, it is a matter of good scientific practice, accountability and openness towards the general public. The question of how to deal with 'deep' uncertainties and limits to its quantification is central in several fields that aim to improve the science-policy and science-society interfaces (Guimarães Pereira et al., 2006). These fields are evolving around different concepts and notions, such as complexity (Chu et al. 2003), resilience (Holling, 1973), post-normal science (Funtowicz and Ravetz, 1993), trans-disciplinarity (Thompson Klein et al., 2001) and the precautionary principle (EEA, 2001; Cooney, 2004; UNESCO COMEST, 2005; Van der Sluijs, 2007). However, many scientists believe that the general public is unable to conceptualise uncertainties and that providing the public with information on uncertainty would increase distrust in science and cause panic and confusion regarding the risk (Frewer et al., 2003). In contrast, focus groups with citizens have shown that citizens in such a group context can take part in differentiated debates about complex environmental issues that are blurred by uncertainties (Kasemir et al., 2003). Furthermore, psychological studies revealed no average change in perceived risk when providing uncertainty information (although, for example, some forms of presentation made it easier for people to either refute a risk or justify heightened concern) (Kuhn, 2000). However, clear and responsible communication on uncertainties, whether addressed to professional policymakers or the general public, is difficult and not always appreciated. The interest of target audiences often seems limited or variable over issues and time. Uncertainty information is often considered difficult to understand, and strategic use is possible (people may use it merely to further their personal goals, for example, by ignoring/trivialising or emphasising it; see e.g. Hellström, 1996; Blanke and Mitchell, 2002; Neutra et al., 2006; Michaels, 2005). Various approaches to the communication and presentation of uncertainty have been developed, but not all are easy to understand by non-technical audiences, and they can also unexpectedly lead to misinterpretation.

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2001) offered two forms of communication on uncertainties: the use of words to reflect different levels of certainty (probability or confidence), and the use of graphics (Moss and Schneider, 2000; Ha-Duong et al., 2007; Swart et al., 2009). The verbal approach used a seven-point scale of terms of likelihood that a particular statement is true: extremely unlikely (<1%), very unlikely (1-10%), unlikely (10-33%), medium likelihood (33-66%), likely (66-90%), very likely (90-99%), and virtually certain (>99%). A similar, five-point scale was used for confidence, together with a quadrant depicting “level of consensus” and “amount of evidence”. The more recent IPCC Guidance Notes (IPCC, 2005) and IPCC Working Group I Summary for Policymakers (IPCC, 2007a) for the Fourth Assessment Report implement several changes, for instance, the “medium likelihood” label was replaced by “about as likely as not” (although this category was not applied in the main conclusions). Alternatives to the IPCC scale exist, for example, the twelve-point Weiss scale, which describes the level of certainty in terms of the degree to which evidence is convincing (Weiss, 2003, 2006), and the seven-point scale by Renooij and Witteman (1999) and Witteman and Renooij (2003). The advantage of using words is that people are better at hearing/reading, using and remembering risk information described in words, rather than in numbers. However, using words results in loss of precision, and words have different meanings for different people (Wallsten et al., 1986), resulting in broad ranges of probabilities associated with each term by different members of the audience (Wardekker and Van der Sluijs, 2005; Wallsten et al., 1986). On the other hand, this disadvantage may remedy the tendency of experts to be overly precise and underestimate the uncertainty associated with their own predictions (cf. Slovic et al., 1981). Broad ranges and wordings may more accurately reflect the limited state of knowledge. A fixed scale’s consistent use of language (fixing probability terms to probability intervals) makes it easier to remember and consistent messages are perceived as more credible. A disadvantage is that a fixed scale does not match people’s intuitive use of probability language. As Patt and Schrag (2003) have shown, people translate such language by taking the event magnitude (severity of effects) into account[25]. For example, an ‘unlikely’ hurricane is interpreted as less likely (in percentage of probability) than an ‘unlikely’ rain shower. This may result in an overestimation of the probability of low magnitude events and an underestimation of the probability of high magnitude events, when a fixed scale is used for communication. Problems appear to be most pronounced when dealing with predictions of one-time events, where probability estimates result from a lack of

[25] It should be noted that in many fields of science and policy (e.g. scenario analysis, safety policy, etc.) *risk* is the crucial evaluative figure, which includes both probability and severity.

complete confidence in the predictive models. In general, the context of an issue influences the interpretation and choice of uncertainty terms (see e.g. Wallsten and Budescu, 1990; Flugstad and Windschitl, 2003; Patt and Schrag, 2003; Patt and Dessai, 2005; Wardekker and Van der Sluijs, 2005). Another issue concerning the use of scales is that it favours attention to quantifiable and probabilistic uncertainty. It is much harder to address ‘deep uncertainty’ (e.g., problem-framing uncertainty, methodological unreliability or recognised ignorance) (Wardekker and Van der Sluijs, 2005; Petersen, 2006; Risbey, 2007).

Surprisingly little research has been done on graphical communication, the main exception being Ibrekk and Morgan (1987). Some general remarks can be made. Graphical communication has the advantage of conveniently summarising significant amounts of uncertainty information (Ibrekk and Morgan, 1987; Wardekker and Van der Sluijs, 2005; Krupnick et al., 2006). Its major disadvantage is that most graphical expressions are not straightforward to understand. Especially when communicating with people who are not used to working with these expressions, this may become problematic. Policymakers prefer simple forms of communication, such as probability density functions (PDFs) and tables, rather than the complex graphics commonly used and favoured by analysts (Krupnick et al., 2006). Graphs can also easily mislead the user. In general, displays that explicitly contain the information that people are looking for, perform best. As with the verbal approach, communication of deep uncertainty seems difficult (Wardekker and Van der Sluijs, 2005).

The Netherlands Environmental Assessment Agency (current Dutch acronym: PBL; until May 2008: MNP – which is used here) has been actively reflecting on its assessment and communication of uncertainties over the past few years. It is a government funded agency that performs independent scientific assessments and policy evaluations of human impact on the environment. Until 2006, it was affiliated with the Dutch *National Institute for Public Health and the Environment* (RIVM). The reflection process was initiated by discussions in media and politics on the reliability of modelling studies (Van Asselt, 2000; Van der Sluijs, 2002; Petersen, 2006), followed by calls to more systematically address uncertainty. A “Guidance for Uncertainty Assessment and Communication” (Van der Sluijs et al., 2003; Janssen et al., 2005; Petersen, 2006) was developed by MNP/RIVM and Utrecht University. The MNP applied the Guidance in the Environmental Balance 2005 (MNP, 2005b). The MNP’s Environmental Balance (“State of the Environment”) reports are yearly reports, describing the state of the (Dutch) environment and evaluating policy influences. National-level policymakers are the main target audience of these reports. This paper presents and analyses a series of experiments evaluating uncertainty communication in the Environmental Balance 2005. These experiments were also meant to generate input for the MNP. The experiments aimed at answering the following questions: How do target audiences perceive uncertainty and its communication? How do they use uncertainty information? What are their needs and desires with respect to uncertainty information? What is their opinion on the present practice of uncertainty communication in the Environmental Balance? How do several existing and new forms of presentation perform, and how could they be improved?

The first part of this paper (Sections3-4) deals with views on, and demand for uncertainty information/communication. The second part (Section 5) deals with how to best present this information. This paper present results from a number of experiments. To improve readability, the sections containing the results include both direct experimental results and their interpretation (preventing the need for readers to continually refer to various earlier sections when reading the interpretations).

5.2. Methodology

The MNP and Utrecht University initially explored the issue of uncertainty communication during an Expert Meeting with 19 international experts on uncertainty, assessing the state-of-the-art and promising experiments for future research (Wardekker and Van der Sluijs, 2005). The meeting provided the basis for the experimental set-up of this study (Table 5.1).

This meeting was followed by several communication experiments, employing two methods: computer-assisted workshops at Utrecht University's Policy Laboratory and an electronic survey (Kloprogge and Van der Sluijs, 2006a,b; Wardekker and Van der Sluijs, 2006a,b,c; Kloprogge et al., 2007). The Policy Laboratory is a meeting room designed for computer-assisted meetings, using a Group Decision Support System (GDSS) (Turban and Aronson, 1998; GroupSystems, 2002). Computer-facilitated workshops are similar to focus groups, but structured and enhanced with various interactive tools. Participant input can be collected using, for example, surveys or various brainstorming tools. Input can be prioritised, categorised, or returned to the participants, for use in discussion or for collecting additional input. An advantage of computer-assisted discussion over normal discussion is that more input can be collected in a shorter time and that more vocal participants will not drown out other participants' input. This method was employed because it allows for a real-time exchange of opinions, feedback of results, brainstorming and discussions. A drawback is that it only allows for a small number of participants and is time-consuming, for both participants and researchers. Electronic surveys allow for more participants and can be less time-consuming, but do not allow for interaction and brainstorming. The survey was used to complement and check results from the workshops in a larger and more diverse group. The workshops used combinations of surveys (quick opinion gathering with multiple-choice, agree-disagree (five-point scale), allocate-100-points, and short open questions), brainstorms (more thorough collection and exchange of opinion), and discussion. A handout containing examples of, for instance, presentation formats was used during some parts of the workshops. The electronic survey employed both multiple-choice and open questions.

Table 5.1. Overview of research setup.

Design	Experimental workshops		Validation
	Exploratory	*Targeted*	
1. Expert meeting uncertainty experts	2. Workshop scientists 3. Workshop students	4. Workshop policymakers 5. Workshop policy advisors	6. Survey

The first workshop was a case study with 13 experts on particulate matter (Kloprogge and Van der Sluijs, 2006a). It intended to collect views on uncertainty communication (experiences, content and criteria) from a researcher/expert's point of view and used the MNP Guidance for Uncertainty Assessment and Communication (Janssen et al., 2005) to structure the discussion. The particulate matter case was chosen because of its topicality in the Netherlands. The second workshop had the character of a try-out and focused on the Environmental Balance, using a convenience sample of 9 undergraduate students in a course on risk management (Kloprogge and Van der Sluijs, 2006b). The workshop intended to experiment with people unfamiliar with the context of the studies (Environmental Balance reports, uncertainty), spotting problems with presentation formats and fine-tuning the experimental design for the targeted workshops.

Participants in the experiments that followed, were users of the Environmental Balance, and were chosen from the complete list of people to whom the MNP had distributed a copy of the Environmental Balance 2005 (n≈3000). Within this population we identified several subgroups of interest to sample from for the workshops and survey: national policymakers at ministries (n=197), regional and local policymakers (n=102), and stakeholders and policy advisors active in the science-policy interface (n=148).

The third workshop included seven policymakers (Wardekker and Van der Sluijs, 2006a). Policymakers are the Environmental Balance's main target audience and, therefore, a key group to include in this study. This group of seven policymakers was put together by random and non-random sampling from the subgroups "national policy makers" and "regional and local policy makers". The non-random factor in the sampling favoured those policymakers that had an active involvement in reviewing draft texts of the Environmental Balance (this subgroups of n=10 was identified in close consultation with MNP). They received invitations in writing and by telephone. From the remaining subgroup of policymakers participants were randomly selected and invited by email. It was difficult to find policymakers who were willing to invest 4 hours of their time to participate in the workshop (non-random factor in the sampling: bias towards those who would have an interest in the subject), and who would be available at the time of the workshop (random factor in the sample). To increase their willingness to participate, they were offered the prospect of a book token of 25 Euros in return for their efforts, and reimbursement of travel expenses. The Hague was chosen as the location for the workshop, very close to the ministries to minimise the travelling time for the participants.

The fourth workshop included nine policy advisors, who were mainly professional consultants (Wardekker and Van der Sluijs, 2006b), strongly involved in the science-policy interface. The sampling was done as follows: from the subgroup "stakeholders and policy advisors" we invited people who are considered active users of the Environmental Balance, and based our selection on the requirement of a diversity of affiliations. This led to about 40 invitations. Within the workshop there turned out to be an overrepresentation of professional consultants, compared to NGO representatives. This apparently stemmed from their greater willingness to participate and their availability on the date set for the workshop.

The electronic survey included 29 respondents (two respondents did not reply to the multiple-choice questions and, therefore, are not included in presented quantitative results). It was conducted among all identified subgroups, and included policymakers (59%) and representatives from science, NGOs, companies and other organisations (Wardekker and Van der Sluijs, 2006c).

5.3. Perception of uncertainty and uncertainty communication

According to the modern view of scientific policy advice, science informs policy by producing objective, valid and reliable knowledge (Funtowicz, 2006). However, uncertainty is a fact of life and for many contemporary complex science-related policy issues, uncertainty significantly limits the degree to which science can provide objective, valid and reliable knowledge (Funtowicz and Ravetz, 1990, 1993; Funtowicz, 2006). People have different views on the extent to which science can remove uncertainty and is certain and objective, and the role and challenge of science, facing uncertainties in policy problems. Views can be classified, using a four-point scale of archetypes of attitudes towards uncertainty, ranging from strict "positivism" (science is objective) to strict "constructivism" (science is inseparable from society and, thus, always coloured by the context in which it is produced), adapted from Van der Sluijs (2005):

- Avoid: Uncertainty is unwelcome and should be avoided. The challenge to science is the elimination of uncertainty by means of more and better independent research.

- Quantify: Uncertainty is unwelcome but unavoidable. The challenge to science is the quantification of uncertainty, and separating facts and values as effectively as possible.
- Deliberative: Uncertainty offers chances and opportunities. Uncertainty puts the role of science in perspective. Science is challenged to contribute to a less technocratic, more democratic public debate.
- Science as player: The division between science and politics is artificial and untenable. Science is challenged to be an influential player in the public arena.

To assess the attitudes among the different groups, all participants were asked (a priori) to indicate which view would best describe their own. The majority of workshop and survey participants selected “Quantify”, a large minority chose “Deliberative”, and a few outliers decided on one of the other options. However, scientists held the “Deliberative” view more often than policymakers. These results should be viewed with some caution due to the limited size of the sample. The question was also posed among a larger sample group, at a Dutch national conference on dealing with uncertainty in policymaking (see Figure 5.1) (Wardekker et al., 2008c). The outcome seemed to confirm the earlier result that scientists held a more “Deliberative” view than policymakers, however, the sample turned out to be too small to result in statistically significant differences (χ^2 test, $p<0.18$). The actual ratio of people selecting “Quantify” and “Deliberative” in the conference experiment should not be generalized, as the attendants made up for a convenience sample, with likely a more positive attitude towards uncertainty than the ‘average’ scientist or policymaker. In the workshops and survey (n=65) the ratio was roughly 3:1 in favour of “Quantify”.

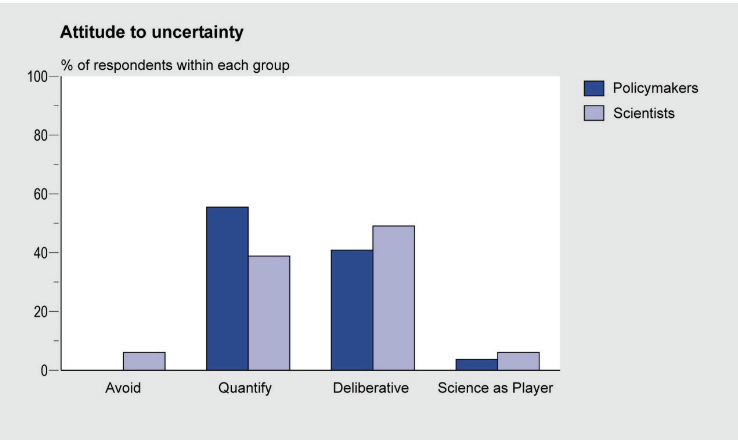

Figure 5.1. Attitudes towards uncertainty (*n*=118). Source: Wardekker et al. (2008c).

The workshop and survey participants considered uncertainty information to be important to policymaking, scientific and societal debate, and to their own work. However, they noted that uncertainty information should be politically and policy relevant, as well as clear, understandable, diverse and precise. Policymakers expressed that assessment reports, such as the annual Environmental Balance, should not contain every nuance of uncertainty, but put forward only the most relevant messages. Uncertainty information was seen as important to put issues on the agenda, to prioritise them, and to phase the policy process. The workshops and survey also revealed other applications of uncertainty information, including: (1) to more realistically assess the effectiveness and efficiency of policy measures, (2) to be used as an argument in support of one's own conclusions and to undermine proposals that do not suit one's interest or agenda, (3) to weigh information and the risks of using information (which may turn out to be incorrect), (4) to determine the desirability of actions, (5) to estimate the plausibility of scenario's and trends, and (6) to develop a vision on future government policy (e.g. development of new policies, or estimating risks for corporate management). Participants noted that providing uncertainty information prevents false certainty, waste of money, and decisions based on insufficient information. We found that policy advisors use uncertainty information for finding policy options and they considered it useful for clarifying options, choices and opinions.

While considered important, uncertainty information has its drawbacks. According to the participants, it can lead to difficulties in negotiations and weaken policy proposals. An "overdose" could, in their opinion, paralyse and lead to unnecessary discussion and delay of action. Selective and strategic use of uncertainty information was said to be a problem in many cases. Some participants also considered interpretation and use of uncertainty information to be difficult in their own daily practice. Preliminary results from another study indicate that policymakers often were not aware of uncertainty information, or did not know how to deal with it. Consequently, the actual use is limited (De Vries, 2007). Several policy advisors and survey participants considered it problematic that uncertainties are often stressed in environmental issues, while little or no uncertainty is communicated in other policy domains (e.g. economy). According to participants, this can give the impression that environmental issues and policy are much more uncertain than those of other policy domains[26], while this is not necessarily the case. Moreover, added complexity due to uncertainty information may confuse the general public. Finally, some suggested that uncertainty communication could also be seen as a way for researchers to avoid giving definite answers. Despite these issues, transparency was deemed highly important.

[26] Similarly, new policy proposals which include uncertainty information could appear more uncertain than previous strategies without such information.

5.4. Demand for uncertainty information

Uncertainty information has various target audiences. A clear choice of target audience, or at least the most important audiences, is highly important for 'what and how' to communicate uncertainty in an environmental assessment. The Environmental Balance reports are intended for national policymakers. Consequently, while policymakers were fairly content with the amount and type of uncertainty information in the document, policy advisors noted that "the information in the Environmental Balance does not cater to the needs of people working with numbers" (Wardekker and Van der Sluijs, 2006b).However, such a mismatch is not necessarily a problem. The policy advisors were well aware that the main target audience (policymakers) had different information needs. The advisors could obtain their information from other sources.

5.4.1 Interest in uncertainty information: general and specific topics

Survey respondents were asked to indicate on which topics they would like to see uncertainty information in the Environmental Balance, for themselves, and for the main target audience (policymakers). Interest was surprisingly broad. Selecting from a list of topics, survey respondents (*n*=27) expressed most interest in uncertainty information on environmental effects of policy (70% for themselves, 74% for the target audience), reaching policy goals (63% for themselves, 70% for the target audience), and severity of environmental problems (67% for themselves, 59% for the target audience). They expressed the least interest in uncertainty concerning environmental quality (33% for themselves, 37% for the target audience) and in expected future policy developments (22% for themselves, 41% for the target audience). Differences between their own interests and those for the main target audience remained small, probably due to the large percentage of policymakers in the sample. Participants in the policymakers workshop were mainly interested in uncertainty information on reaching policy goals. They considered this to be the main topic of the Environmental Balance. However, they noted that uncertainty information should be much broader for environmental issues which are topical, controversial, or relatively new.

Furthermore, workshop and survey participants were asked to suggest specific topics on which they would like more uncertainty information. Three main categories could be discerned: topical issues (e.g. air quality and particulate matter, which have received much media attention in the Netherlands due to problems with meeting European standards), issues on which there is little to no uncertainty communication while uncertainties do play an important role (e.g. external safety and flooding hazards), and matters which are important for finding, selecting and prioritising policy responses (e.g. sources and types of uncertainty, differentiation in time and spatial scale, and uncertainties in health effects of various environmental stressors). Policymakers as well as policy advisors considered uncertainties surrounding the economic effects of policies to be important. The policy advisors disagreed with the policymakers' preference for the focus of uncertainty information in the Environmental Balance to be on reaching policy goals, and they called for a much broader set of topics. In particular, they called for more explicit information on the solidity of the presented numbers, for instance, by adding a margin of accuracy, to make policymakers more aware of the sometimes limited solidity and accuracy of presented numeric information.

The policy relevance of uncertainty information on various topics around a particular environmental issue, depends on the issue's stage in the policy cycle. Upon recognition of a problem and agenda setting, information related to fundamental issues such as problem framing, level of scientific understanding, methodology, environmental quality, causes and impacts is relevant. During policy formulation, uncertainties around impacts, emission data, scenarios, and expected policy effects (environmental, economic, social) are relevant. During the implementation and monitoring/control phases, uncertainties around emission data, projections, environmental quality, and actual and expected policy effects are important. Questions from earlier phases regain relevance when policy is evaluated, or when an issue is topical or controversial. The choice of the target audience is again important. For example, differentiation in spatial scale may be relevant to actors at a regional level, but may provide too much information for a national level. One could publish information that is relevant for audiences other than the primary target audience in, for instance, a background document.

Based on the workshops and earlier experiences, the following situation-specific factors[27] can be posed, which may increase the policy relevance of uncertainty: (1) when being wrong in one direction could carry more serious consequences than being wrong in the other (also see Manning et al., 2004), (2) when uncertain outcomes can have a large influence on policy advice, (3) when indicators are close to policy goal or threshold, (4) when there is the possibility of large effects or catastrophic events, (5) in cases of societal controversy, (6) when value laden choices are in conflict with interests or views of stakeholders, and (7) when public distrust in outcomes that show low risk can be expected.

[27] The precautionary principle (UNESCO COMEST, 2005; Van der Sluijs, 2007; Cooney, 2004) is an often suggested heuristic for policymaking in situations characterized by one or more of these factors.

5.4.2 Sources and types of uncertainty

The policy advisors emphasised particular interest in the various types and behind-the-scenes causes of uncertainties, such as modelling-uncertainty and scenario-uncertainty. They noted that insight in these aspects is relevant for finding and selecting policy responses, for example, monitoring or performing more research on specific issues. In their workshop, policymakers noted that uncertainty is a much more complex issue than becomes apparent from the graphs and texts of the Environmental Balance. Aspects, such as uncertainties due to the quality and accuracy of monitoring techniques and level of knowledge, play a role, as well as the origin and/or use of models, scenarios, worldviews, values, and underlying assumptions. Or, as one respondent in the survey noted: "uncertainty is often translated in terms of absence of risk, but it should also be about issues such as uncertainty about the hypothesis, the empirical data, and about fundamental issues, such as the chosen methodology and the posed causal relations" (Wardekker and Van der Sluijs, 2006c). The survey respondents (n=27) were asked whether the Environmental Balance should pay more attention to the sources/causes and different types of uncertainty. Many were positive (30% agreed, 11% strongly agreed), but just as many were hesitant (30% neutral, 15% do not know/no opinion). The consulted policymakers were unsure whether users of the Environmental Balance would be interested in such information. Most of them preferred this information to be added to the appendices, not the main text of the report, except for when it concerned topical issues. One person noted that it would be useful to add a description of the origin of the uncertainties.

5.4.3 Implications of uncertainty

Policy advisors considered sources and types of uncertainty to be important issues, because of the implications for policy. However, a policymaker noted that it is not always clear why knowledge of the uncertainties is important. Survey respondents (n=27) were strongly in favour of paying more attention in the Environmental Balance to the implications of uncertainty: 37% strongly agreed and 37% agreed. Apparently, many participants consider sources and types of uncertainty important, but they, typically, would prefer the MNP to incorporate this information more directly into the implications. In general, the way in which such an incorporation could be done, depends on the objectives of the assessment organisation. In the end, policymakers are making the policy decisions, whether or not implications of uncertainty have been included in the assessments. However, it remains useful to reflect on the *possible* implications of uncertainties, thereby providing decision makers with some perspectives on how to deal with those uncertainties.

5.4.4 Recalculations

Another issue pointed out by the workshop participants, is the phenomenon of recalculations. That is, recalculating and modifying *past* estimates (e.g. emission data), based on progressing insights. A striking example of this, is the Dutch ammonia emission data for the year 1995, as reported in the Environmental Balances between 1996 and 2002 (see Figure 5.2). The effect of the recalculations of these data is of the same order of magnitude as the 2002 2σ interval (technical uncertainty, not including methodological uncertainty) (Honingh, 2004). The policymakers considered this phenomenon to be very confusing and noted that the Environmental Balance does not always show clearly that recalculations were done, or why. Most survey respondents (*n*=27) agreed with the policymakers that the Environmental Balance should pay specific attention to this phenomenon: 19% strongly agreed, 53% agreed, and 22% remained neutral.

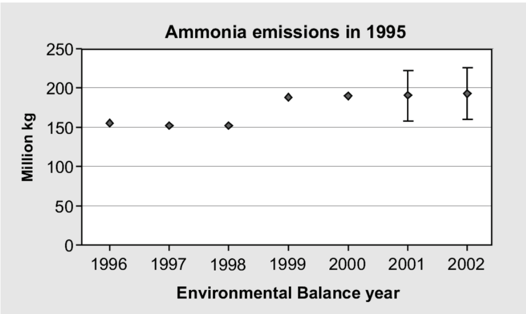

Figure 5.2. Dutch ammonia emissions in 1995, as reported in different Environmental Balances. Error bars indicate 2σ intervals (technical uncertainty, first reported in 2001). Honingh (2004).

5.5. Presentation of uncertainty information

Authors make choices on whether uncertainty information is presented by using text or graphs, on its place in the report, and the way in which it is communicated. Several approaches, current and new, were evaluated during the workshops and survey. This section deals with several issues of interest related to presentation: probability terms, presenting different types of uncertainty, qualitative aspects of uncertainty, and the place of uncertainty information in reports.

5.5.1 Probability terms

In the Environmental Balance 2005, the MNP systematically communicates uncertainties by using, among other things, a fixed scale of probability terms (translation of the IPCC scale), coupled with colour codes. The IPCC scale is easy and appealing, as it is already widely used. However, it's central term, "medium likelihood" (33-66% probability), proved to be problematic in use and translation. Apparently, its use is disputed within IPCC, as well. The Uncertainty Guidance Notes for the Fourth Assessment Report replaced the term with "about as likely as not" (IPCC, 2005), and the WG I Summary for Policymakers used "more likely than not" for 50-66% (IPCC, 2007a). Literal translation to Dutch would result in "middelgrote waarschijnlijkheid", but the MNP opted for "fifty-fifty; circa 50%" (derived from "tossup" in Morgan (2003)). Earlier studies have shown that people's interpretation of probability terms results in broad ranges of estimated probabilities (e.g. Wallsten et al., 1986; Morgan, 1998, 2003). During the workshops and survey, several experiments were conducted on how the terms of the IPCC scale are interpreted. The scale already attaches a range to a given term, rather than a single probability. The experiments aimed to determine whether people's interpretation of various probability terms matched the range provided by IPCC. On the one hand, participants were given various probability terms (intended for the range of 33-66%) and asked to estimate a probability range (…% to …%). On the other hand, people were given the probability range of 33-66% and asked to provide a suitable term for this range. These participant-designed terms were then tested in later workshops and the survey.

Participants' interpretations of various terms are shown in Figure 5.3. The figure shows the ranges of lower and upper border estimates and the median for each estimate. "Fifty-fifty" performed reasonably well, most estimates being 40-60% or 45-55%. Several people indicated that it could be anything, placing the range at 0-100%. Individual estimates of policymakers and students were dominated by one answer, resulting in medians at the ranges' extremes. With an overall median estimate of 40-60%, the term was interpreted more narrowly than intended. The term "circa even waarschijnlijk als onwaarschijnlijk" (IPCC's new "about as likely as not") performed similarly, the difference being several estimates of a flat 50%. The term "middelgrote waarschijnlijkheid" (IPCC's old "medium likelihood") did not do well. Estimates of the lower border ranged from 0 to 80%, of the upper border from 25 to 100%. The median estimate was 50-75%; higher than intended. When asked to suggest a term for the interval of 33-66%, suggestions diverged greatly, ranging from "cannot be determined" to "to be expected" to "not to be expected". The two possibly suitable terms ("very well possible" and "to be expected") were tested in the survey. They did not perform well, considering the overlapping lower and upper border estimates, and high medians.

If the Dutch experiment is any indication of interpretation of the English terms, IPCC's switch to "about as likely as not" seems a good move. While this term performed well, "medium likelihood" did not. The results also show that, while terms such as "fifty-fifty; about 50%" and "about as likely as not" result in broad estimated ranges, these ranges match IPCC's probability range fairly well. As these terms were interpreted somewhat more narrowly than the intended range, it could be useful to provide additional information in cases where probability can be placed near the borders of the range. Discussion and comments during the workshops and survey suggested that the diversity in participant-suggested terms might be due to differences in perceived need for additional policy. This would be consistent with literature findings, which indicate that choice and interpretation of terms depend on context (Wallsten and Budescu, 1990; Flugstad and Windschitl, 2003; Patt and Schrag, 2003; Patt and Dessai, 2005). For example, interpretations can depend on expected impacts, expected effectiveness of policy measures, or strategic considerations.

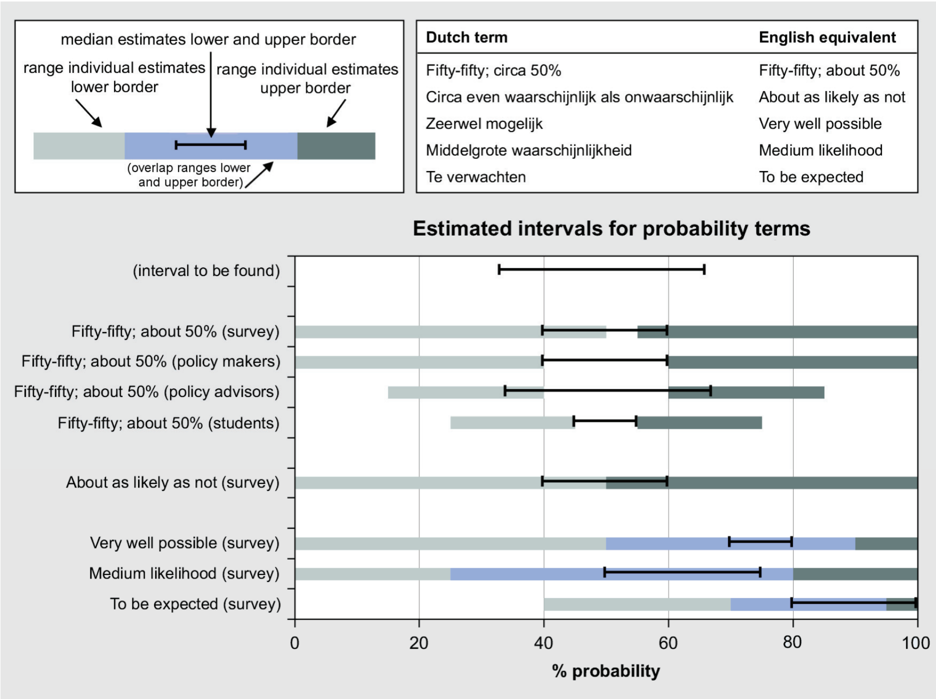

Figure 5.3. Estimated probability intervals (…% to …%) for 'medium likelihood' terms.

5.5.2 Presenting different sources of uncertainty

Two sources of uncertainty, which are communicated in environmental assessments, are projection-uncertainty (uncertainty in prediction of future emissions) and monitoring-uncertainty (uncertainty in measurement of emissions). The MNP elected to communicate only the projection-uncertainty in cases of relative policy goals (e.g., reduction of emissions with x% compared with that of year y), and to communicate both projection-uncertainty and monitoring-uncertainty in cases of fixed goals (reduction of emissions with x tons compared with that of year y). Monitoring-uncertainty, which is calculated as a fixed percentage of emissions, is less relevant to a relative goal, as it is assumed to be the same percentage in both reference and goal year. However, it is relevant when a goal is fixed, as changes in emissions to those of a reference year change the required policy effort. Figure 5.4 shows both situations.

During the workshops, experiments were conducted in which participants were confronted with figures presenting either projection-uncertainty or monitoring-uncertainty, or both (e.g. Figure 4a as presented above, as well as a version that included monitoring-uncertainty), with and without textual explanation of what was included and/or why. Participants were asked a series of closed and open-ended questions to determine their understanding and interpretation of the graphs, followed by discussion of the results. Conclusions from the workshop were then tested during the survey, by means of multiple-choice questions.

In the graphs, it is not always clear what is communicated, and why and when. However, both sources of uncertainty have different strategies for reducing uncertainty and different policy implications. Textual explanation proved difficult to interpret due to the technical nature of this issue; for example, the differences between the two sources of uncertainty and the reasons for including them or not, required thorough explanation. Several of the workshop participants remarked that the problem with the above reasoning of which source of uncertainty to include, is that relative targets tend to become fixed targets later on, for example when an emission ceiling is set and emission rights are granted. The participants in the survey and those in the workshops with policymakers and advisors all wanted the MNP to communicate both the projection-uncertainty and the monitoring-uncertainty, regardless of the type of goal. However, policymakers and survey respondents thought that monitoring-uncertainty should be placed in the appendices, unless it had direct consequences for policy. Respondents differed on whether these uncertainties should be communicated within the same or in different graphs, but agreed that a distinction should be made. Suggestions included a set of three graphs (projection, monitoring, both), an online interactive graph, and adding projection-uncertainty as grey area around the projection and monitoring-uncertainty as an error bar.

5.5.3 Qualitative aspects of uncertainty

'Deep' uncertainties cannot be easily quantified or expressed probabilistically and are hard to communicate using traditional methods, such as probability terms, uncertainty ranges, and error bars. Among these uncertainties are qualitative issues, such as problem framing, choice of methods, general level of knowledge and value-ladenness. The participants expressed an interest in such information. Both verbal and graphical approaches, dealing with these qualitative aspects, were included in an evaluation of various presentation formats, during the workshops and survey. Respondents were asked, using closed and open-ended questions and open discussion, to evaluate these approaches on several criteria and to voice initial impressions and interpretations.

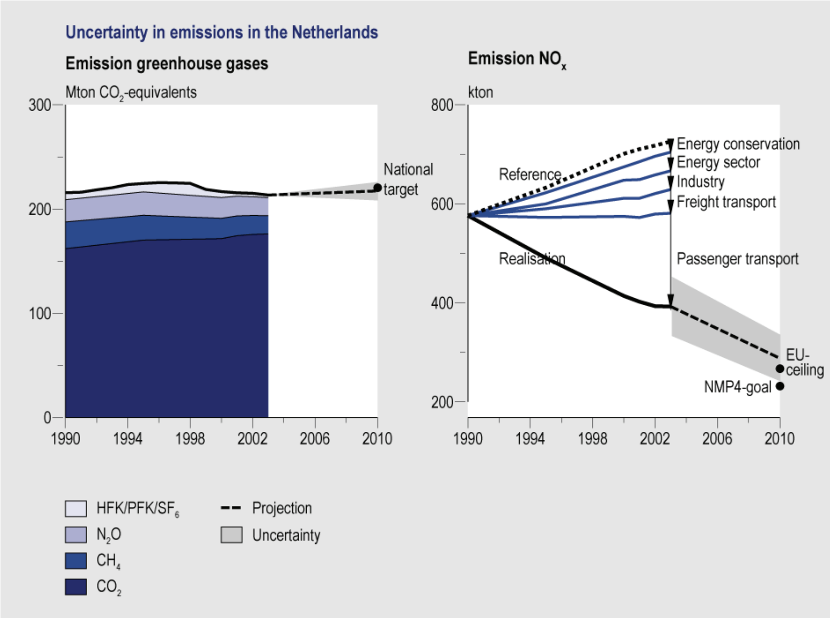

Figure 5.4. (a) Projection-uncertainty in greenhouse gas emissions. (b) Monitoring-uncertainty and projection-uncertainty in NO_x emissions (arrows indicate contribution of five policy measures that have been implemented since 1990). Modified from MNP (2005b).

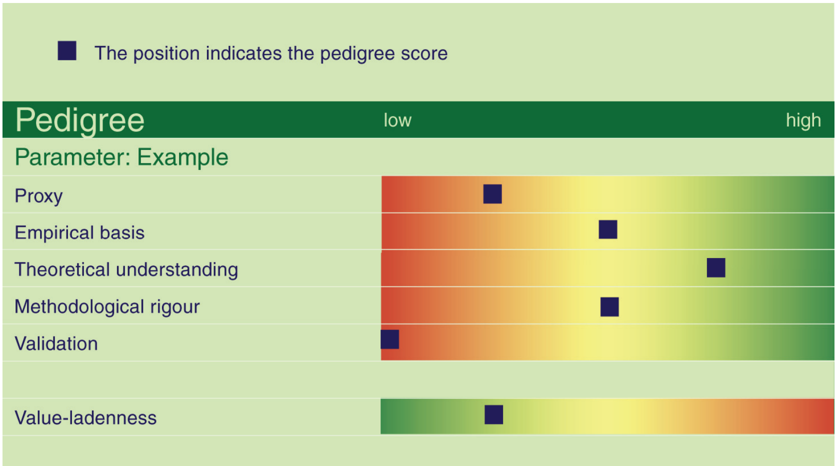

Figure 5.5. Example pedigree chart. Gradient ranges from red (low) to green (high). For value-ladenness, this is reversed.

One verbal approach to communicate qualitative aspects is to add a level-of-knowledge indicator. The wording in the graph of radiative forcing due to various greenhouse gasses, in the IPCC Third and Fourth Assessment Reports (IPCC, 2001, 2007a), is a well-known example. The graph lists the "level of scientific understanding" (LOSU) for each forcing under the graph using the scale “high, medium, low, very low”. A similar MNP graph was tested in the policy advisors workshop. A more extensive verbal approach would be to provide a section of text on qualitative uncertainties.

Another approach is to use graphics. One could rate several qualitative aspects of uncertainty and depict them in diagram. The NUSAP system for uncertainty assessment includes such a “Pedigree” Assessment, in which the strength of research results is evaluated, looking at the background and foundation of these results (Funtowicz and Ravetz, 1990; Groenenberg and Van der Sluijs, 2005; Van der Sluijs et al., 2005a,b,c). A set of qualitative criteria is rated, by means of individual expert judgments, on a scale of 0 (weak) to 4 (strong) giving a description of each rating on the scale. The criteria may vary, depending on the audience and case at hand. Common criteria include: quality of proxy, empirical basis, theoretical understanding, methodological rigor, validation, and value-ladenness. The results can be plotted in, for example, a radar diagram or kite diagram (Moss and Schneider, 2000; Van der Sluijs et al., 2005a). In practice, these figures revealed several problems: they are not straightforward to understand, and can be misleading as they invite to compare area sizes, while these strongly depend on the arrangement of the criteria in the graph (Wardekker and Van der Sluijs, 2005). A new approach was developed during the workshops: the Pedigree Chart (see Figure 5.5). Average pedigree scores are placed on a gradient of red to green (bad to good). Margins (e.g., ‘error bars’) can be added to reflect the range of individual expert scores. The chart uses the same traffic-light analogy as a kite diagram, but is easier to interpret and less likely to mislead.

Participants considered the level-of-knowledge indicator to be a useful approach, but noted that it suggests a correlation between the level of understanding and the uncertainty in data presented in the graph (e.g., the error bars in the radiative forcings in the IPCC graph). However, this is not necessarily the case. Furthermore, the approach is fairly simplistic and does not provide insight in the background of the uncertainties, policy implications or strategies to reduce uncertainties. Policymakers liked to be provided with some background text on qualitative aspects, but preferred such information to be placed in the appendices, except for topical issues.

The policy advisors were very enthusiastic about the Pedigree Chart. According to them, it gives a quick overview of qualitative uncertainties and is very useful for relativising presented data. The majority would like to see such graphs in the main text of the Environmental Balance. However, the present criteria (Proxy, Empirical basis, etc.) would require explanation, or could be replaced by more straightforward alternatives. More than half of the survey respondents (*n*=27) agreed that such figures should be added to the Environmental Balance: 7% strongly agreed, 44% agreed, 19% remained neutral, 19% disagreed. The respondents were divided on whether such figures should be added to the main text. Survey respondents preferred the graphical approach above adding the textual information.

During the workshop, the policy advisors stressed the importance of presenting qualitative aspects of uncertainty; they observed that policymakers tend to regard the numbers presented in the Environmental Balance as solid information, while the solidity of those numbers is often questionable. Here, we encounter the tension between what policymakers expect and/or prefer (solid quantitative information) and what scientists can deliver, which was also observed in Section 3.

5.5.4 The place of uncertainty information in reports

The participants in the policymakers workshop preferred only a limited amount of directly policy relevant information in the main text of documents. Other information should be placed in appendices or other reports. However, when asked whether they had read the Environmental Balance's appendix on uncertainties (Appendix 3 from MNP, 2005b), none had done so. Many of the policy advisors, however, wanted as much uncertainty information in the main text as possible, increasing its visibility to the policymakers. They emphasised that the presented information should be relativised, as policymakers often overestimate its rigidity. Important uncertainty information should be placed both in the general summary and in the chapters or the chapter summaries/conclusions, as policymakers often read only certain chapters of reports, depending on the relevance to their policy field. Furthermore, policy advisors considered it useful to add a short introduction, early on in the report, on how it deals with uncertainty. This helps readers attune to the concept of uncertainty and the communication formats that are used. Crucial information, such as the explanation of probability terms, should not be left to the – often unread – appendices.

As noted earlier, not all uncertainty information will be relevant to the main target audiences. However, principles of good scientific practice, the presence of other interested target audiences, and the fact that other uncertainty information may become relevant at a later point, call for the communication of additional information as well. An approach to dealing with the dilemma of what to communicate and where, is the concept of 'Progressive Disclosure of Information' (PDI) (Guimarães Pereira and Corral Quintana, 2002). This approach entails implementing several "layers of information" to be progressively disclosed, from non-technical to more specialised, according to the needs of the user. In environmental assessments, these layers could be the summary, conclusions, chapter summaries/conclusions, main text, appendices, and background material, such as background reports or additional online information. Uncertainty information that is deemed to be highly relevant to the main target groups should be placed in the summary and conclusions, while other material could be added to the main text, appendices, or background material, in order of relevance. Background material, available in appendices and from other sources, should be clearly referred to, indicating their existence and location. Some general guidelines are suggested in Table 5.2. For detailed guidance on how to apply Progressive Disclosure of Information in practice, see Kloprogge et al. (2007).

Table 5.2. Suggested general guidelines on the contents, style and degree of detail of reported uncertainty information at different PDI (Progressive Disclosure of Information) layers.

	Outer layers	Inner layers
Contents:	Uncertainties can be integrated in the message (implicit, using words such as "may" or "might")	Uncertainties mentioned separately and explicitly
	Uncertainties as essential contextual information on the assessment results	Uncertainties as part of scientific accounting on the approach used in the study and on the assessment results
	Uncertainties translated to the political and societal context	Account of the 'untranslated' uncertain-ties from a scientific point of view
	Emphasis on policy relevance of uncertainties	Balanced account of uncertainties in all parts of the assessment
	Emphasis on implications of uncertainties	Emphasis on nature, extent and sources of uncertainties
	Implications of uncertainties for the assessment results and the policy advice given	Implications of uncertainties for the representativeness of a study, value of the results, and further research
Style:	Scientific information translated into 'common language'	Scientific information with a high technical sophistication
	Use of jargon to be avoided	Use of jargon allowed
Degree of detail:	Details only if considered policy relevant	Highly detailed (each layer offers more detailed information than the previous)

5.6. Discussion

5.6.1 Limitations of the analysis

In the previous Sections, several remarks on the statistical representativeness of the various samples were made. In view of the objective of our study, our primary concern is societal and political relevance and not technically defined representativeness, per se. For this reason, several biases in our study can also be seen as advantages and not only as limitations. We aimed at involving competent and engaged participants who are well in touch with the groups they represent.

Research efforts tend to attract respondents who are interested in the subject and used to working with it. Participants may, therefore, have a more positive attitude towards uncertainty and communicating uncertainty than the "average" audience (that is, the majority of readers of an assessment report). Those who do not favour such activities may consider research to hold little relevance to them. One policymaker noted in an e-mail, declining participation, that he considered uncertainties to be "annoying" in daily practice and that people "shop selectively" and interpret and use the information to further their own goals, making communication of uncertainty a waste of effort. However, an indication that the participants were indeed representative for the larger target audience, is the fact that many of the participating policymakers were sent by their departments, to represent the department's collective views.

In evaluating presentation formats, respondents who had experience with uncertainty may have found the formats easier to interpret, compared to an "average" audience. Furthermore, the research subject brought the uncertainty information into focus, as would not happen in casual reading, which might result in easier interpretation, as well. Nevertheless, participants would likely be able to differentiate between the more straightforward and more difficult formats, to estimate interpretation by less experienced colleagues, and to offer suggestions for improvement. However, it would be useful to check specific presentation formats, perhaps in a study not focused on uncertainty, by conducting additional experiments with educated laypersons (such as the students in this study).

The generally limited amount of respondents, is another issue. Participation takes time, people often felt their (departmental/organisational) views would be better represented by others, or they considered themselves only distantly related to uncertainty communication or to the contents of the Environmental Balance. While policymakers seemed to be adequately represented, would have been interesting to have had more input on individual/personal views and views of NGOs, companies and politicians.

Finally, calls for information on specific issues and aspects of uncertainty are likely to vary for different assessments, countries and topics, due to varying economic, social, environmental, and political situations (cf. Geert Hofstede's concept of "uncertainty avoidance", one of five dimensions of differences in national cultures; see, e.g., Hofstede, 2001). Visser and Petersen (2009) present a specific Dutch example of uncertainty communication regarding climate change impacts on ice-skating marathons, showing the contextual dependence of uncertainty information. In the present study, we identified a strong call for uncertainty information on particulate matter, as it is highly topical in the Netherlands. Issues, such as probability terms, are strongly language-dependent. The reported results can be seen as indicative of other configurations/countries, but the extent to which these results can be generalised remains to be determined.

5.6.2 Implications for the practice of uncertainty communication

Perceptions in the science-policy interface, on how to deal with and communicate uncertainty vary strongly (see also Van der Sluijs, 2005, 2007). For example, is it important to provide uncertainty information, and should this information preferably be quantified? Many contemporary policy issues can be characterised as 'post-normal':

facts are uncertain, values in dispute, and the decision stakes high (Janssen et al., 2005; Van der Sluijs, 2002, 2007; Van der Sluijs et al., 2008). In such situations, explicit attention for uncertainty and knowledge quality is important. Policy processes demand information at short notice, but users of this information often do not have a clear view of the research behind it and its complexities, caveats, and robustness. Policymakers were surprised by the many aspects of uncertainty, and policy advisors noted that policymakers tend to see numbers as 'solid facts'. Nuances in information may be obvious to scientists, but not to policymakers and, therefore, need to be made explicit.

Uncertainty information may indeed add to the complicatedness of already complex problems. However, simply not providing such information or relegating it to background reports would not add to the quality of these decisions. Quantitative, as well as qualitative uncertainty information is required. This is particularly true in policy settings, where time is limited and many assumptions are required for quantification. Moreover, (yet or principally) unquantifiable uncertainties can be highly policy-relevant. Qualitative information can provide insight in, for example, research priorities, scenarios of plausible futures and development pathways, and 'deep' uncertainties (e.g. problem-framing uncertainty, methodological unreliability or recognised ignorance). Unquantifiable uncertainties can take the forefront in societal debate. As the policy advisors in this study noted, policymakers will need information to be prepared for this.

A way forward for uncertainty communication is to improve its tailoring to the users of this information. In environmental assessments, its role is not merely 'good practice', but to support societal decision-making. To enhance usability, the communicator will need to keep in mind the decision problem that the user faces. Different uncertainties are relevant to different people, in different situations, and in different stages of a policy cycle. In some cases, it may be sufficient to compound different uncertainties into a single range (black box); in other cases it could be useful to segregate them to reveal different levers for improving the odds. Furthermore, policymakers strongly called for information on the implications of uncertainty. This does not mean that scientists should tell policymakers what to do, but that they should provide them with useful insights, to help them make their decisions. For example, provide information on the consequences for the solidity of the conclusions and the policy risk (probability and consequences) of wrong decisions. In 'fifty-fifty' situations, policymakers were more interested in how much they might exceed a target (and how to limit this), than in the exact probability of meeting such a target. Perhaps integrating probability, severity, and reduction possibilities (cf. EEA, 2005, p.15) could prove useful, also for overcoming the problems of interpreting probability terms.

5.7. Conclusions

This study explores the views, held by various parties in the Dutch science-policy interface hold, on uncertainty, uncertainty communication and its use and usefulness. Most participants preferred a quantifying approach to uncertainty. In this view, uncertainty is undesirable, but inevitable and science should quantify uncertainty and separate facts and values. However, in practice this is often difficult and unrealistic in complex issues where facts are uncertain, values in dispute and the stakes high. This means that there is a mismatch between the degree of certainty that science can realistically deliver in such a situation, and what science is expected to provide. A large minority of the respondents opted for a deliberative view: uncertainty creates opportunities and puts the role of science into perspective. Differences between scientists and policymakers in such perceptions of uncertainty and tensions, between what is expected from science and the limits to quantification of uncertainty, should be anticipated in communication strategies. Participants considered uncertainty information to be important to policymaking and the scientific and societal debate, but it should be concise and policy relevant. Policy relevance depends on, for example, the place of an issue in the policy cycle, novelty, topicality, controversiality, and several situation-specific factors. However, political interest is often limited, and uncertainty adds additional complexity and difficulty in daily practice (interpretation and use) and in negotiations, and the possibility of strategic use.

Participants had a broad interest in information on various types of uncertainty. They were particularly interested in uncertainty in (1) the environmental effects of policy, (2) reaching policy goals, and (3) the severity of environmental problems. Furthermore, they called for more uncertainty information on (4) topical issues, (5) issues on which there is little uncertainty communication at present, and (6) matters that are important for finding, selecting and prioritising policy responses. Specific information needs reported by participants included: sources and types of uncertainty, implications of uncertainty, and the phenomenon of recalculations. Reflection on possible implications of uncertainty seems especially important, considering reported difficulties in interpretation and use of uncertainty information, lack of clarity on why it is important to be aware of (specific) uncertainties, and a strong perceived need for such information.

The use of probability terms – as is done by for instance the IPCC – is problematic, since differences in interpretation are large and context-dependent. The term “medium likelihood” for 33-66% probability seems especially problematic. Participants’ estimates for a direct Dutch translation varied greatly (median: 50-75%). Translations of the newly introduced terms “about as likely as not” (IPCC, 2005; IPCC, 2007a) and “fifty-fifty; about 50%” (MNP, 2005b) were also studied. The present study is the first to empirically assess these two new terms. The performance of both terms turned out to be fairly good (median: 40-60%), which implies that they could effectively to communicate what is meant.

Respondents were interested in information on the different sources of uncertainty that play an important role in a particular environmental problem. For instance, information on both projection-uncertainty and monitoring-uncertainty was found useful. The different types of uncertainty appeared to be relevant for assessing different policy questions. The monitoring-uncertainty is sometimes not communicated, as it is less relevant for relative policy goals. However, relative goals tend to develop into absolute goals, for which monitoring-uncertainty is relevant. Thus, it depends on the policy setting, first, which sources of uncertainty should be taken into account and, second, which sources of uncertainty could be aggregated.

Qualitative aspects of uncertainty are deemed relevant to policy. They can be communicated using a simple verbal "level of scientific knowledge" indicator or a more comprehensive graphical Pedigree Chart. Writers of environmental assessments should carefully consider where to place uncertainty information in the report. Information should be progressively disclosed depending on its relevance to target audiences. Crucial information (e.g. for interpreting how the report deals with uncertainty) should not be placed in often unread places, such as the appendices.

Most participants were positive about the amount and clarity of uncertainty communication in MNP's Environmental Balance reports, but several suggestions for improvements have been made. These include the issues described in this article, as well as more specific suggestions, which can be found in the Dutch background documents. Overall, a responsible communication of uncertainty information leads to a deeper understanding and increased awareness of the phenomenon of uncertainty and its policy implications. It is expected that this understanding and awareness may result in a more responsible, accountable, more transparent – and ultimately more effective – use of intrinsically uncertain science in decision-making.

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Chapter 6.

Frame-based guide to situated decision-making on climate change

Abstract
The present paper describes a frame-based approach to situated-decision-making on climate change. Building on the multidisciplinary literature on the relationship between frames and decision-making, it argues that decision-makers may gain from making frames more explicit and using them for generating different visions about the central issues. Frames act as organizing principles that shape in a "hidden" and taken-for-granted way how people conceptualize an issue. Science-related issues, such as climate change, are often linked to only a few frames, which consistently appear across different policy areas. Indeed, it appears that there are some very contrasting ways in which climate change may be framed. These frames can be characterized in terms of a simple framework that highlights specific interpretations of climate issues. A second framework clarifies the built-in frames of decision tools. Using Thompson's two basic dimensions of decision, it identifies the main uncertainties that should be considered in developing a decision strategy. The paper characterizes four types of decision strategy, focusing on (1) computation, (2) compromise, (3) judgment, or (4) inspiration, and links each strategy to the appropriate methods and tools, as well as the appropriate social structures. Our experiences show that the frame-based guide can work as an eye-opener for decision-makers, particularly where it demonstrates how to add more perspectives to the decision.

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6.1. Introduction

The complexities of climate change are confronting decision-makers with different sorts of "reality". During much of the past three decades, for example, they had to deal with a reality in which climate change mitigation and adaptation were sharply separated both in science and in politics. Back in the 1980s, as Kellogg (1987) mentioned, preventing (or delaying) the change and adapting to the change were depicted as the two decision tree branches that showed the whole range of policy choices. In contrast to prevention, adaptation was the option for both sceptics and fatalists (Thompson and Rayner, 1998). Recently, however, adaptation, and more particularly, a strategic approach to adaptation has been recognized as an essential part of climate policy by scientists (Pielke et al., 2007) as well as by policy-makers involved with the United Nations Framework Convention on Climate Change (UNFCCC, 2007) and the World Business Council on Sustainable Development (WBCSD, 2008). The contrasting interpretations of adaptation reflect crucial differences in the frames that shape how individuals and institutions conceptualize the relevant aspects of an issue. Climate change science and policy may especially be issues that can be framed and reframed in several ways (Nisbet, 2009; Robinson et al., 2006; Schlumpf et al., 2001). Although decision-makers may not simply be able to change their frame at will (Thompson and Rayner, 1998), it is important for them to be made aware that "taken-for granted" frames, including the frames that are "built-in" in decision tools, can subtly shape their conceptions of reality. Also, decisions may gain from making frames more explicit, for instance, by looking at weak signals through various scenario lenses (Schoemaker and Day, 2009) or by reflecting on the frames that underlie controversy (Schön and Rein, 1994). Based on the multidisciplinary literature on this topic, the present paper will examine how frames can be made more explicit in the context of decision strategies for climate change adaptation.

Frames are the topic of research in such varied fields as anthropology, linguistics, cognitive psychology, social and organizational psychology, management science, sociology, communication and media studies, social movements research, policy science, science studies, and philosophy. Although there are slight differences between various definitions (Barsalou, 1999; Chong and Druckman, 2007; Goffman, 1974; Graf, 2006; Schön and Rein, 1994), frames are generally conceived as organizing principles that enable a particular interpretation of a phenomenon. As Fillmore and Atkins (1992) note, frames can often be created by or reflected in the language. For instance, references to specific patterns of climate change manifestations, such as "changes in snow" or "sea level rise", may activate a frame of semantic knowledge relating to the event. Because the frame of a complex event is never experienced directly in its entirety, subsets of frame information will become active to highlight some potentially relevant aspects (Barsalou, 1999). In the present example, climate change manifestations can be framed in an event-like structure that combines aspects regarding scene, agency, location and time-line. Hence, the frame may include the aspects “attribution to climate change” (which may be likely or unlikely), “identifiable places” (e.g. existing or latent), “time horizon” (e.g. short- or long-term), and possibly also “uncertainty about science” (e.g. high or low), “uncertainty about politics” (e.g. high or low) and “source of information” (e.g. trusted or not). Within this frame, the climate change manifestation can be understood as a specific co-occurring set of relevant aspects, e.g. “changes in snow” may be linked to a combination of “likely attribution”, “identifiable place”, “short time horizon”, “low uncertainty”, and “sea level rise” to a combination of “likely attribution”, “latent place”, “long time horizon”, and “high uncertainty”. Also, within a frame each aspect may be associated with its own frame and more specific sub-aspects (e.g. variants of uncertainty); this dynamic relational structure makes frames flexible and context dependent.

Climate change manifestations have become increasingly salient to decision-makers and the public at large. As several authors (Dempsey and Fisher, 2005; Halsnæs et al., 2007; Kirshen et al., 2008) emphasize, however, decision-making on adaptation should take into account that the expected impacts of policy options on society tend to be very context specific. This is partly due to the complexities of climate change itself, which may cause considerable uncertainty over climate change projections and its impacts (Dessai and Hulme, 2004; Lempert et al., 2004). Also the role of other human-caused environmental changes, such as changes in regional land use patterns, can make a large difference to the end result. In particular, it is the specific combination of climate change and other environmental changes that may create the most significant impacts for society. Consequently, decision-makers should develop a strategy that is informed by a rich store of information and, at the same time, ensures a sufficient degree of flexibility and adaptability (Lindblom, 1990; Thompson and Tuden, 1959; Thompson, 2003). Whether their strategy for decision-making leads to adequate action will strongly depend on the way in which they frame the specific aspects of the situation, such as co-occurring sets of “time horizon” and “uncertainty” (Robinson et al., 2006; Schlumpf et al., 2001). For instance, instead of focussing on the question “How can we reduce uncertainty in our estimates of future climatic conditions?” it may be important to give more attention to the question “Given that there is considerable uncertainty about our future, how can we best manage this coastal area to reduce risk and increase system resilience?” Hence, situated decision-making may well be facilitated by making frames and frame-based decision strategies more explicit and using them for generating different visions about the central issues.

After a short elaboration of frame analysis – in particular regarding frames that are relevant for discussions on science-related issues, such as climate change – the next sections of the paper will address some critical choices and assumptions of decision-making. One of the most important choices is selecting a decision strategy, which, in turn, may shape the choices of appropriate methods and tools, as well as the social structure that fits the process. Our approach has been developed in interaction with a number of adaptation projects at the regional and local level. These projects were supported by a large national research programme in the Netherlands that is built around the principles of climate-proofing (see Kabat et al., 2005). It aims to bring scientists and practitioners together in the context of selected "hotspots", such as the Port of Rotterdam and the Province of Groningen (see below). Our work has resulted in a frame-based guide to situated decision-making.

6.2. Frames applied to science-related issues

6.2.1. Frame analysis

Enabling the actors involved in decision-making to figure out what the crucial frames are is a challenging task. Frames can be expressed by various representations, such as how a problem is stated, who is expected to make a statement about it, what questions appear relevant and what range of answers might be appropriate. However, frame analysis is often hampered by the difficulty of unravelling the sheer flexibility and context-dependency of frames (Barsalou, 1999; Goffman, 1974). As mentioned before, the frame of an abstract term, such as a concept, an event, or a plan, is never experienced directly in its entirety. Even in hindsight, professional skill and knowledge may be required to carefully reconstruct the event-like structure of an environmental discourse (Hajer, 1995; Moser, 2005). However, there is room for a more strategic approach, since frames are based on a shared cultural background of experiences, beliefs and practices. One option is to look at a strategic level for contrasting patterns of perception and communication. For example, the increasing salience of climate change manifestations sharply contrasts with the conceptualizations of climate change in terms of abstract and distal properties that were common in the recent past (Bord et al., 1998). The term "distal" (versus "proximal") here and in the following text relate to having a more long-term (versus short-term) focus. The contrast between perceptions focused on distal and on proximal threats agrees with patterns of differences between distal and proximal levels of thinking (i.e. abstract versus contextualized) that have been reported in the literature (Liberman and Trope, 2008; Wakslak and Trope, 2009) and that are also of relevance for the interpretation of climate issues.

Another set of contrasts can be recognized when social actors try to influence each others' frame by using particular communication symbols (framing devices, see

Gamson and Modigliani, 1989). Important symbols include metaphors (e.g. Spaceship Earth), historical examples from which lessons are drawn (e.g. the most dramatic recent disaster), and visual images (e.g. picture of a polar bear). By adopting one of the frames they attempt to open certain positions in favour or against an issue. Presumably, much about this role of frames can be learned from the voluminous work that has been done in the field of science and technology controversies. Social scientists who have analyzed public discussions on (policy relevant) science-related issues argue that these issues are often linked to only a few frames, which consistently appear across different policy areas (Gamson and Modigliani, 1989; Nisbet, 2009). For example, synthetic pesticides, such as DDT, have been framed as a blessing for humanity (before the year 1962), but also as “Pandora's box” (after the publication of Rachel Carson's Silent Spring in 1962), as a matter of specific risks and benefits to be decided on scientific evidence (with the rise of ecotoxicology as a science in the 1980s and 1990s), and as a key factor to keep certain industries competitive (along with each new pesticide regulation). These contrasts between promotion and prevention strategies can be linked to broader literature on goal-directed behaviour (Higgins, 1997; Higgins, 2000) and people's attitudes towards interventions in the natural world (De Boer, 2010).

6.2.2. Contrasting interpretations of climate-related issues

The frames applied to science-related communication suggest that two strategic contrasts can lay the ground for a simple framework to highlight interpretations of climate-related issues. The first contrast is the difference between a promotion or prevention orientation to goal-directed behaviour; the second involves taking a distal or proximal view on an object. The two are combined in Table 6.1. After a short explanation of this framework, it will be applied to various ways in which climate-related issues are being framed.

Table 6.1. Two strategic contrasts combined.

Perceptual distance	Goal orientation and focus	
	Promotion orientation	Prevention orientation
Distal view (long-term, broad categories)	Using broad categories to represent general features and focusing on gaining positive outcomes (hits)	Using broad categories to represent general features and focusing on avoiding negative outcomes (errors)
Proximal view (short-term, narrow categories)	Using narrow categories to represent contextualized features and focusing on gaining positive outcomes (hits)	Using narrow categories to represent contextualized features and focusing on avoiding negative outcomes (errors)

Generally, a promotion orientation makes the person sensitive to positive outcomes and hits (as opposed to errors) that may be gained through aspirations, accomplishments, and ideals (Higgins, 1997; Higgins, 2000). In contrast, a prevention orientation makes the person sensitive to negative outcomes and errors that have to be avoided by fulfilling one's moral obligations and responsibilities. This difference is not just a matter of personal mindsets – the orientations can be associated with certain institutions, subcultures within an organization, or occupational groups. Engineers, for example, are said to be safety oriented and inclined to “overdesign” for safety (Schein, 1996).

In line with the second contrast, taking a distal (versus a proximal) view on an object may evoke broad categories to represent its general features rather than its more contextual and incidental aspects (Liberman et al., 2007). This may include more abstract moral principles to judge the object. In contrast, a proximal view induces categories that are narrower to represent more detailed and contextualized features. A proximal view is more constrained by concrete realities and it may very well go together with intentions to implement a plan (Goldstone and Barsalou, 1998). Again, these perceptual differences also have cultural relevance. They are closely related to differences between holistic and analytical ways of thinking, each of which may have become more useful and more available in one culture than in another. For instance, Easterners tend to engage more in holistic perceptual processes whereas Westerners tend to engage more in analytical ones, but this preference should be seen as a matter of default (Nisbett, 2003).

Building on this framework, Table 6.2 captures the different frames that may underlie discussions on science-related issues and provides relevant examples. Table 6.2’s upper right cell represents a distal approach to prevention orientation. Prevention-oriented frames aim to avoid errors in dealing with, for example, the earth's atmosphere or with climate change adaptation. This may be combined with broad categories of thinking about moral aspects of climate change. Al Gore's movie “An Inconvenient Truth” fits well into this pattern, calling for precaution in the face of potentially catastrophic impacts. Regarding the rise of the CO2 concentration and the extrapolation thereof into the future, Gore noted that “Ultimately, this question is not political, but a moral issue …. If we allow that [the extrapolated rise] to happen, it is deeply unethical”. He continued to describe various impacts that may occur when climate change remains unchecked, and noted that future generations will judge our actions today (“what were our parents thinking?”). Gore often stressed certainty and scientific consensus; other Christian voices in the public debate on climate change diverge on what is the most ethical way forward. In the United States, various groups and commentators discuss climate change as an ethical issue related to intergenerational equity, the implications for the poor, and the relation between humankind and nature (Wardekker et al., 2009b). While the groups diverge in their assessments of policy strategies and the pro's, con's, outcomes, and fairness of these, they – including the climate-sceptical ones – use very similar ethical starting points and imagery (e.g. stewardship over “God's garden” and passing on the “gift of creation”).

Table 6.2. Science-related frames (adapted from Nisbet, 2009) grouped into four strategic contrasts, with examples about climate issues.

Perceptual distance	Goal orientation and focus	
	Promotion orientation	**Prevention orientation**
Distal view (long-term, broad categories)	*Social progress frame* Defines the issue as improving quality of life or harmony with nature. *Middle way frame* Puts the emphasis on finding a possible compromise position between polarized views. Example: Plan to reconcile adaptation and mitigation.	*Morality/ethics frame* Defines the issue in terms of right or wrong; respecting or crossing limits. *Pandora's box frame* Defines the issue as a call for precaution in face of possible impacts or catastrophe. Example: Al Gore's movie: An inconvenient truth.
Proximal view (short-term, narrow categories)	*Economic development frame* Defines the issue as investment that improves competitiveness. *Conflict/strategy frame* Defines the issue as a game among elites, a battle of personalities or groups. Example: climate proof city.	*Scientific uncertainty frame* Defines the issue as a matter of what is known versus unknown. *Public accountability frame* Defines the issue as responsible use or abuse of science in decision-making. Example: sea level discussion.

The work of the Intergovernmental Panel on Climate Change (IPCC) and the national report of the second Dutch Deltacommittee (Deltacommissie, 2008) on flood safety in the Netherlands take a more proximal view of prevention orientation (lower right cell of Table 6.2). The Deltacommittee report aimed to develop an integrated vision for the Netherlands for centuries to come. Despite the report's long time horizon, it has a narrow, specific, concrete focus, for example, on specific sea level scenarios. The report details the latest scientific insights on specific changes, their impacts, and possible policy options. As the uncertainty associated with projections on such long timescales is very large, the committee explored the plausible upper limits of regional climate changes (sea level rise and river discharge in particular) for the Netherlands. They assessed, through modelling, the implications thereof for long-term water safety and fresh water supply. This upper-limit scenario assumed a global mean temperature rise of 6 °C in 2100 and accelerated sea level rise through rapid non-linear melting response to warming of the Greenland and Antarctic ice sheets. The report's publication stimulated a lively public debate on dealing with scientific uncertainty in designing long-term policy strategies. For example, many wondered whether the recommendations should be followed, considering the fact that the assumed scenario was considerably more extreme than the national meteorological institute's national climate scenarios. This debate on specific sea level scenarios distracted somewhat from the long-term vision-development that was intended. In contrast to the more holistic vision and viewpoints expressed in the report's chapter headings (e.g. “developing with the climate”), many of the recommendations were, in fact, fairly top–down engineering and implementation-oriented, such as national scale flood safety regulations and dike improvement, a mechanism to warrant long-term availability of financial means required to maintain flood safety under the extreme sea level rise scenario, and the appointment of a national “delta director”.

Both prevention-oriented frames contrast with two promotion-oriented frames. Promotion-oriented frames highlight the possible gains that climate-related issues can entail for society. A proximal example of this is the notion of a “climate-proof city” such as expressed in the city of Rotterdam, the Netherlands (lower left cell of Table 6.2). The city, which host Europe's largest seaport, is adjacent to the North Sea, at the mouth of the river Rhine, and includes dike-protected areas below sea level as well as areas outside the dike defence zones (at 2.5–5 m above sea level). It is expected to face numerous challenges due to climate change. However, the municipality aims to establish a strong economy and attractive city. Being (and clearly appearing) well prepared for climate change is considered an important factor in promoting these aims (see e.g. Wardekker et al., 2010). The city aims to be a frontrunner on both adaptation and mitigation. It emphasizes and advertises various strengths and ambitions, such as innovative action, initiative and leadership, reframing climate change from a “threat” to an “economic chance”. In our workshop with local actors, many practical adaptation options were generated using concepts such as climate-proofing, resilience, and water as opportunity for urban development. In 2007, a city-wide programme, the Rotterdam Climate Initiative (RCI), was created to realise the ambitions, provide a concrete action plan (with clearly defined goals), and monitor the progress. The RCI includes partners such as the city's municipal departments, the port authority, the local environmental protection agency, and the local employers’ organization.

A more distal, promotion-oriented approach (upper left cell of Table 6.2) may be typical for attempts to reconcile potentially competing policy objectives, such as climate change mitigation and adaptation. At the regional level, this approach was taken in the north of the Netherlands, where the sea-bound “Hotspot Groningen” project was led by the Province of Groningen. The project, at the interface between sea level adaptation, sustainable energy options and spatial planning, was designed by a landscape architect. In our workshop with regional actors, he emphasized that the concept of “growing with the trends” (versus “blueprint planning” to resist them) should play an important role to make the region climate-proof, and more generally “future-proof”. The project's activities included stakeholder dialogues and creative workshops, as these were considered more suitable for structuring “wicked problems” and developing and creating societal support for options than “scientific analysis”. Initially, the findings were intended to inform the Provincial Environment Plan, which provides the legal basis to integrate plans with respect to environment, traffic and transport, water, and spatial planning. However, tensions seemed to exist between the Hotspot project and the setup of the Plan. Although the Plan started with a phase of searching for inspiration regarding desirable futures, vision-development was replaced relatively quickly by an approach that focused on proximal intentions. The switch of frames may be attributed to the desire of the provincial deputy to have measurable targets that are legally enforceable. Although members of the Hotspot team were honoured with several international awards for their advanced planning concepts and designs, the provincial strategy has, in fact, moved from the upper left cell of Table 6.2 to the lower right cell.

Taken together the four cells of Table 6.2 can improve our understanding of the various ways in which climate issues may be framed. In addition, the contrasting features of the four cells indicate that none of the frames is a stand-alone guide to an adaptive choice. Each frame has its strengths and weaknesses in articulating the specifics of a situation. Prevention may have to be complemented with promotion (or vice versa), and the distal view of broad strategic planning needs a more implementation-oriented, proximal way of thinking about how measures can be organized. Hence, introducing a contrasting frame may be used to open-up the process of decision-making.

6.3. Frames built-in in decision tools

6.3.1. Decision strategies

In the process of decision-making, frames will have crucial impacts on the selection of a decision strategy. This refers in particular to those aspects of a particular frame that highlight uncertainty about science and uncertainty about politics. In other words, the question is whether the actors involved in decision-making need more scientific knowledge and/or more deliberation on preferences. These questions can fruitfully be addressed using Thompson's seminal approach to strategy development. According to Thompson, the two basic dimensions of decision are beliefs about (1) the cause/effect relations that are instrumental for what the decision might actually accomplish and (2) preferences regarding the possible outcomes of the decision (Thompson and Tuden, 1959; Thompson, 2003). Depending on the specifics of the situation, both dimensions can take a range of values. However, for the sake of clarity of the presentation, they are often dichotomized; i.e. the actors involved in decision-making perceive certainty or uncertainty regarding causation and certainty or uncertainty regarding outcome preferences.

Table 6.3 presents the patterns of uncertainty of the two dimensions. Whether cause/effect relations are believed to be uncertain may depend on several conditions, such as the actors' beliefs that the existing knowledge is incomplete, that there is inherent uncertainty or uncertainty due to competition with opponents (e.g. rivals in the market). Outcome preferences can become uncertain in situations where a single individual or organization appears to hold multiple, opposing preferences regarding the outcomes of possible actions. An additional type of uncertainty occurs when there are external constraints that make the actors involved in the decision dependent on others who hold veto power over some possible preferences. This may happen where regional decision-making is restricted by strategic planning processes that are coordinated by governmental institutions and other agencies (Few et al., 2007). In sum, Table 6.3 may be very helpful in telling complete stories about uncertainty, including quantitative and qualitative aspects of uncertainty (Patt, 2007; Van der Sluijs et al., 2005; Van der Sluijs et al., 2008).

Table 6.3. The two basic dimensions of decision combined to identify different decision strategies (after Thompson, 2003).

Beliefs about cause/effect relations	**Preferences regarding possible outcomes**	
	Certain	**Uncertain**
Certain	Causation and outcome preferences are certain, data are voluminous *Computational strategy*	Uncertain due to – Opposing preferences – External constraints *Compromise strategy*
Uncertain	Uncertain due to – Incomplete knowledge – Inherent uncertainty – Competition with rival decision-makers *Judgmental strategy*	Uncertain due to – A combination of reasons from the upper right cell and the lower left cell *Inspirational strategy*

Table 6.3 also provides logical links between uncertainties and strategies of decision-making. Actors who are confronted with uncertainties regarding causation and outcome preferences should adapt their decision strategy to these issues (Thompson and Tuden, 1959; Thompson, 2003). Provided that there is at least a certain degree of commitment to reaching agreement, they may choose one of the four types of decision strategies.

- If the actors believe that there is enough certainty regarding both causation and outcome preferences, decision-making is relatively straightforward, although it may require a computational strategy to process voluminous data (upper left cell of Table 6.3).
- If outcome preferences are clearly known and shared but cause/effect relations are uncertain or disputed, the actors must rely on a judgmental strategy to find a solution (lower left cell of Table 6.3).
- In contrast, if cause/effect relations are certain but outcome preferences are uncertain or disputed, the actors need a compromise strategy to identify an acceptable preference (upper right cell of Table 6.3).
- Finally, if both causation and outcome preferences are uncertain or disputed, the most likely action of the actors is to avoid any decision on the issue, unless an inspirational strategy can be introduced to create a new vision or belief (lower right cell of Table 6.3).

6.3.2. Suitable decision tools

Each decision strategy can be elaborated to find methods and tools with built-in frames that fit the strategy. Table 6.4 shows a number of options.

Table 6.4. Methods and tools that are relevant for the decision strategies.

Beliefs about cause/effect relations	Preferences regarding possible outcomes	
	Certain	Uncertain
Certain	*Computational strategy* • Cost-benefit analysis tools • Multi-criteria analysis tools • Accounting tools and physical analysis tools	*Compromise strategy* • Participative tools, e.g. stakeholder analysis and focus groups • Argumentation support tools • Negotiation tools
Uncertain	*Judgmental strategy* • Scenario analysis tools, expert panels, simulation gaming • Model tools (biophysical, socio-economic, integrated) • Checklists for judging model quality and uncertainties	*Inspirational strategy* • Cognitive aids, e.g. checklists for prompting new ideas, “rich picture” drawing • Development of learning-scenarios

A computational strategy (upper left cell of Table 6.4) may rely on conventional forms of decision support, such as multi-criteria analysis tools (MCA) and cost-benefit analysis (CBA). The built-in frame of these methods sees the decision situation as a problem for which an optimal solution might exist, provided that trade-offs will be accepted. The notion of trade-offs can be an argument to opt for a transparent, quantitative evaluation of the options. CBA can identify the most advantageous solution or at least those options for which benefits are greater than the costs, because it may attach a monetary value to every aspect considered relevant to society. In fact, this monetarisation is framed as aggregating independent individual choices in a market context. However, CBA is not adapted to long time horizons (>25 years) and may generate questions about the ethics of interest rates and long-term discounting (Stern, 2007; Turner, 2007).

Alternatively, the decision situation may be framed as a problem whose solution should satisfy a wide set of constraints (upper right cell of Table 4). Following a compromise strategy, the decision-makers may want a course of action that is acceptable to all kinds of stakeholders. To find a common preference, participatory tools can be applied, such as community planning tools, which can be framed as building on deliberative democratic forums (Welp et al., 2006). Such a frame involves some form of open, goal-directed conversation or “dialogue” between decision-makers, experts and other stakeholders, which may create favourable conditions for the exchange of diverging arguments. It should be noted, however, that people with diverging arguments can only communicate meaningfully if their frames overlap to a certain degree (Brockriede, 1992).

Where outcome preferences are clearly known and shared but cause/effect relations are uncertain or disputed, the actors must rely on a judgmental strategy to clarify matters (lower left cell of Table 6.4). It is in particular the nature and the relevance of scientific uncertainty that can lead to difficult discussions between decision-makers and experts, as well as between experts among themselves (Dessai and Hulme, 2004; Lempert et al., 2004). Insight into the strengths and weaknesses of advanced tools such as influence diagrams (including Bayesian Belief Networks) and dynamic models (including computable general equilibrium models) will require an analysis of critical choices and assumptions. Uncertainty about the impacts of the behaviour of other people on the decision's outcomes may require a game theoretic approach.

Finally, an inspirational strategy (lower right cell of Table 6.4) may include tools to stimulate creativity, such as the development of learning-scenarios (Berkhout et al., 2002). In fact, there are two diverging frames of creativity (Nguyen and Shanks, 2009). Some persons, such as the Hotspot Groningen team mentioned before, tend to emphasize the value of spontaneous insight and the magical “Aha!” moment that occurs when a long-sought idea suddenly appears at the conscious level. Other persons emphasize systematic approaches to exploring problems and potential solutions. The occurrence of insight is often associated with restructuring or reframing a problem space, for example, by putting the problem in a broader perspective or by zooming-in on a particular detail. Both approaches should be supported by good preparation and the participation of people who have good knowledge about a particular domain and who are able to think flexibly and synthetically.

6.3.3. Suitable social structures

A closely related strategic consideration is the notion that institutions and groups have organized themselves differently to address different kinds of decision-making problems (Thompson and Tuden, 1959; Thompson, 2003). Hence, when the actors involved in decision-making want to adapt their decision strategy to the uncertainties regarding causation and outcome preferences, they also have to consider the social structures that are appropriate for the issues. Table 6.5 displays the most appropriate social structures for each of the strategies.

Table 6.5. Different social structures that fit the decision strategies.

Beliefs about cause/effect relations	Preferences regarding possible outcomes	
	Certain	Uncertain
Certain	Computational strategy in a bureaucratic structure	Compromise strategy in a representative structure
Uncertain	Judgmental strategy in a collegial structure	Inspirational strategy in an informal structure

A computational strategy that is based on cost-benefit analysis, for example, should take into account that this tool can only be applied in a comprehensive way under specific conditions. Compliance with certain rules and conventions regarding the choice of discount rates is crucial to provide comparative insights into the financial costs and benefits of the options. Accordingly, the most appropriate setting for the use of cost-benefit analysis may be a bureaucratic structure that guaranties that every issue is routed to the appropriate specialist (upper left cell of Table 6.5). If public decision-makers want authoritative statements about the results of computations, these will have to be produced by an official planning bureau or committee (e.g. the Deltacommittee). However, this does not preclude any other groups from using computational tools, such as a simplified or “quick scan” CBA, just for exploratory reasons.

A compromise strategy has to be developed if there is agreement by all parties regarding the expected consequences of the available alternatives but lack of consensus over preferences. From an organizational perspective (Thompson and Tuden, 1959; Thompson, 2003), the most appropriate setting to handle compromise types of issues economically and efficiently is a representative structure of intermediate size that facilitates detailed and subtle exploration of the several preferences (upper right cell of Table 6.5). In complex democratic societies, however, this type of rational problem solving should take into account that there are many ways to frame a representative structure and to develop criteria that include or exclude potential participants. For example, a framing of the “climate proof city” not widely shared by its residents might be contested by individuals and groups who feel excluded (e.g. Owens, 2000). As mentioned before, local decision-making may also be restricted by strategic planning processes that are coordinated at some higher-level (Few et al., 2007). Hence, the social structure will often have to be adapted to fit the local cultural and institutional context in order to work.

A judgmental strategy is called for if causation is uncertain or disputed; this may require a collegial structure, such as a self-governing voluntary group that is competent by virtue of their expertise to make a judgment (lower left cell of Table 6.5). If none of the experts has indisputable and complete evidence, no member should be allowed to outvote or override the judgment made by other members and a majority judgment may be necessary. A specific variant is the Delphi method, which uses a model of “anonymous” interactions in a panel of experts (Kleindorfer et al., 1993). However, what experts often take for granted as anonymous peer review is a frame that may not be shared by all the actors involved in decision-making. Hence, it is crucial that the production of information is not only perceived as credible and relevant but also as legitimate in the sense of being respectful of stakeholders’ divergent values and beliefs, and fair in its treatment of opposing views and interests (Cash et al., 2003).

The fourth type of issue is one in which both causation and outcome preferences are uncertain or disputed (lower right cell of Table 6.5). In fact, these conditions make it difficult for all parties to prevent disintegrating tendencies, such as loss of contact or decreasing commitment to reaching agreement. Therefore, the actors involved may try to avoid any decision on the issue, unless a new vision or belief can be developed (Thompson and Tuden, 1959). Promoting the inspirational aspects of a decision strategy may require an informal setting that offers incentives for collective problem solving. Such a creative kind of activity may be stimulated by charismatic leaders or successful models of new visions. Metaphor development may be a significant step, since metaphors can provide a common language to communicate complex concepts to others and gain their support. The already mentioned case of Hotspot Groningen shows, however, that it is not easy for an informal group of creative professionals to overcome the political constraints of a government institution. Using Snow's notion of “frame bridging” (Snow et al., 1986), it may be said that the informal group was not equipped to bridge the gap between their frame regarding the issue and that of the formal organization.

Generally, decision-makers should take into account that it is important to consider the match between decision strategy and social structure, especially if they want to change their strategy. For example, decision-makers who operate in the context of a bureaucratic structure may not be in a good position for choosing another type of strategy than a computational one. If an organization, such as a governmental agency, adopts one of the four decision strategies as its dominant strategy, it may have to cooperate with other organizations to exercise a different kind of strategy, for example, to involve local stakeholders in a representative structure. Alternatively, it may be necessary to create a novel organization (or committee) to address issues for which traditional structures are ill suited.

Another strategic consideration is the relationship between the science-related frames and the decision strategies. Figure 6.1 illustrates that there may be a loose coupling between the various elements of decision-making. For example, an economic competitiveness frame may give rise to a computational strategy to check the optimum. Similarly, a morality frame may lead to a compromise strategy in order to check the constraints of a morally acceptable solution. A scientific uncertainty frame may require a judgmental strategy to clarify what is known versus unknown. And a social progress frame that aims to reconcile opposing policy objectives may have to be fleshed out by an inspirational strategy. However, these linkages are not the only possibilities and Figure 6.1 can be seen as a heuristic device.

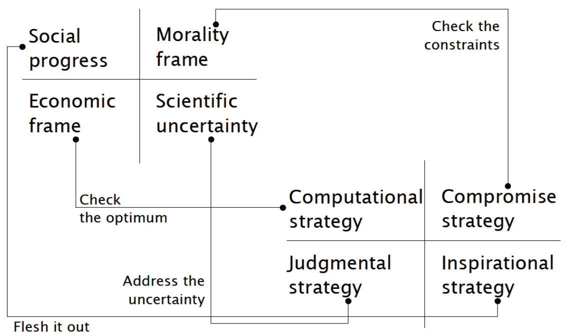

Figure 6.1. Loose coupling between science-related frames and decision strategies.

Our interaction with a number of adaptation projects at the local and regional level showed that the information that is summarized in Figure 6.1 works as an eye-opener for actors involved in decision-making. This relates in particular to the exposé of contrasting frames and the way in which they may open-up decision-making. For instance, experts from knowledge institutes considered it very helpful to separate the various questions they received from policy-makers into question regarding scientific uncertainty and questions about political uncertainty. They used this frame-based distinction to prioritise their research activities and to improve their communication with policy-makers. Based on these experiences we have written a tool catalogue in which we present characteristic examples of how various tools mentioned in Table 4 deal with framing (Wardekker et al., 2009a). The examples are meant to demonstrate that it may be very fruitful to use more than one frame and more than one strategy after another. If the built-in frames are made more transparent, tools can be used as “boundary objects” or focal points around which knowing-in-practice may arise (Spee and Jarzabkowski, 2009); i.e. tools are not only important instrumentally for problem structuring, problem solving and decision-making but also productively to stimulate interaction across professional boundaries and enable sufficiently shared meanings to move forward.

6.4. Discussion and conclusions

This paper has discussed several crucial aspects of frames and their role in decision-making in the area of climate change. Frames can particularly be of help in adding new perspectives to a decision process and in checking whether the participants are able to understand each other. Adding new perspectives may be crucial for several reasons. The first is that it opens up the option space so that new and otherwise overlooked response options may emerge. Another reason is that any complex decision is often nested within a broader set of aspects (Kleindorfer et al., 1993). These aspects may include promotion or prevention oriented objectives, as well as abstract long-term visions and more narrowly defined implementation-related issues. One of the experts in scenario development, van der Heijden (2004), notes that a single stand-alone scenario project does not very often lead to "blinding insights" on what to do. It does not sensitise decision-makers to multiple interpretations of weak signals and may result in what Marx et al. (2007) call the single-action bias, that is a propensity to take only one action to respond to a problem, such as just raising the dikes, in situations where a broader set of remedies is called for, e.g. to make a system more resilient.

Adding new perspectives is also relevant because a single frame will induce a passive acceptance of the information given (Kahneman, 2003). Instead, contrasting frames may be used to stimulate more active participation in decision-making and include groups, such as knowledge producers and stakeholders, who may fruitfully contribute to this process. A careful consideration of frames in their role of organizing principles may lead to a more in-depth understanding of the information tools that can be used to support situated decision-making. This will facilitate a better match between supply and demand of information among all the actors involved, i.e. knowledge producers, decision-makers and stakeholders.

A closely related point is that actors can only communicate meaningfully if their frames overlap to a certain degree. If the frames of two persons share too little, they will be unable to co-operate in the same process and their interaction may result in a "dialogue of the deaf". In the context of climate-related decision-making, however, overlapping frames are not self-evident. The tools that are available to support decision-making have been developed by experts from strongly divergent disciplines, covering both the natural and the social sciences. This divergence may create many frame-based problems. For example, due to the technical nature of computational tools, these decision support tools may become counterproductive if their outcomes cannot be shared with decision-makers and stakeholders who see themselves as problem owners but have fundamentally different frames. If decision-makers and stakeholders do not recognize how their input has been incorporated in the analysis, they will lose their trust in the legitimacy of the information production (Cash et al., 2003).

The present analysis of contrasting frames can be positioned between more cognitive and more political approaches. In a political context, there is at least a genuine tension between actors with different interests and frames, and those of them who have more power have more control over the frames that are being used. However, at points of policy-uncertainty, there are chances for less powerful actors to define the frame, at least temporarily. Because climate change manifestations may contribute to policy-uncertainty, this is an important point, as revealed by the Hotspot Groningen case. What happened in this case has much in common with policy stories described by Schön and Rein (1994: p. 91) about designers who create a policy plan, which they put out into a larger arena, where other actors respond to the plan guided by their more implementation-oriented interests and frames. As they compete to control the plan, it may evolve in ways that differ from what any one of them had intended. Although this seems to be a classic problem of planners versus implementers, it should be taken into account that climate change manifestations may cause many disputes and much uncertainty. This prospect makes it necessary to perform more detailed research into how the problem of planners versus implementers is related to processes of decision-making on climate change adaptation.

One limitation of the paper is that we did not address the issue of managing the decision process. Thompson and Tuden (1959) already referred to process-related problems, such as confusion of issues, structural constraints, inappropriate decision teams and expansion tendencies in decision issues. As decision-makers change their beliefs about cause-and-effect relations, for example, types of issues that at one time are identified as appropriate for a judgment strategy may at another time be defined as computational problems, or vice versa. Also, different decision-makers may respond to the same situation in different ways, some seeing it as a matter for computation, others as a judgment matter, and still others as requiring bargaining. According to Schoemaker and Day (2009) moderate conflict, as opposed to little or extreme conflict, leads to the best decisions, but the conflict must be among ideas, not individuals.

If the issue to be decided is linked to serious pre-existing conflicts, strategy development should first create a more neutral starting point. Even then, however, both a judgmental and a compromise strategy may fail due to increasing tendencies of polarization. The heat of debate can lead experts who endorse a particular solution to overstate their case, discount missing information and refer to moral justification for the solution they prefer. When this occurs, the issue is no longer one of judgment but one of compromise. Similarly, an issue that seems fit for a compromise strategy may generate difficulties in the identification of causation. Next, proponents may discount causation theories endorsed by their opponents and dismiss the corresponding "facts". As a result of this polarization, parties may start to threaten each other with trouble on unrelated matters (Thompson and Tuden, 1959). Obviously, this is precisely what has happened in several climate-related discourses (Kellogg, 1987; Nisbet, 2009).

If sharp conflicts can be reduced or alleviated, reframing may help to open-up the process of decision-making (Schön and Rein, 1994). A crucial way to reframe a situation may result from changes in people's interpretations of a topic. For example, it may be helpful to put climate change adaptation and mitigation in the context of a higher-level objective, such as sustainable development (Robinson et al., 2006), thereby enabling decision-makers to spot options that they initially missed. Emphasizing the functional relationship with sustainable development makes it easier to combine the impacts of adaptation and mitigation with those of other environmental changes. Placing a particular issue in a larger context is not only relevant to handle bargaining issues, but it can also help to crystallize consensus about preferences if the parties involved are unaware of the similarities of their preferences. Alternatively, reframing may occur by means of zooming-in on the actual specifics of a situation, for example, by organizing a site visit to a particular area. This may be the starting point of a more innovative approach to an issue.

An important area of further research is to examine whether the exposé of contrasting frames that was presented in this paper will also be useful in other parts of the world. Although there are many differences between, for example, Asians and Westerners in how they conceptualize the world, these differences are now commonly thought of as different default hierarchies. For example, Westerners are more likely to insist on using formal logic, while Asians are willing to live with more contradiction, but this difference is not absolute (Nisbett, 2003). Moreover, in our approach there is room for both. The first group may see the decision situation as a problem for which an optimal solution might exist, to be found by a computational strategy. The second group may see the decision situation as a problem whose solution should satisfy a wide set of constraints, to be found by a compromise strategy. The main point is that all the actors become aware of these potentially hidden differences.

Overall, our experiences demonstrate that climate change manifestations may induce much uncertainty related to science and policy. In this context, a frame-based approach can contribute to a comprehensive repertoire of methods and tools for adaptation planning and implementation. In particular, presenting more than one frame may work as an eye-opener for actors involved in decision-making. Contrasting frames may be used to stimulate more active participation and enable policy-makers to avoid lock-in on a non-reflected frame. Because each frame may have its strengths and weaknesses in articulating the specifics of a situation, it may be fruitful to use more than one frame after another. In sum, decision-making may gain from making frames more transparent and promote systematic reflection on frames.

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Chapter 7.

Summary and conclusions

Climate variability and change are important factors for societal development. They affect numerous physical, biological and social systems. Projected changes in global mean temperature for the coming century and beyond are expected to have a wide variety of effects on global and local levels. Examples include changes in sea level, precipitation and river runoff, drought, wind patterns, food production, ecosystem health, phenology and species distributions, and human health. Awareness is growing that adaptation to climate change is inevitable. It is the only intervention that could reduce the impacts of climate change foreseen for the coming decennia, before efforts to reduce greenhouse gas emissions (mitigation) will have climatic effects. Analyses of climate change impacts are however associated with numerous and large uncertainties, which are present (and add up) in every step of the analysis. This is particularly the case for the local level projections – while it is exactly these local effects that have considerable societal salience (compared to global average changes). The large degree of uncertainty is a challenging issue in decision-making of climate change adaptation concerning the questions of to what changes and what degree of change should we adapt in order to climate-proof society. How urgent, far-reaching and/or flexible should adaptation measures be?

The literature on approaches to dealing with climate change uncertainties in impact assessment and adaptation is scarce. Various approaches to decision-making regarding climate adaptation have been indicated as being able to address the uncertainties in some ways. Examples of these approaches include: robust decision-making, exploratory modelling, adaptive management, the precautionary principle, no-regret approaches, flexibility, safety margins, virtue ethical approaches, backcasting and outlier analysis, resilience, anticipating design, risk approaches, traditional scenario analysis, and human development approaches. Two main schools of thought can be discerned: top-down (also: 'predict & control', 'optimization' or 'conventional') and bottom-up (also: 'integrated & adaptive' or 'resilience-oriented'). Some 'combined' approaches have been identified as well. Each approach offers some assistance in dealing with uncertainty in a general sense, but there are differences in the levels of uncertainty which they are most suitable for. Predict & control approaches, for example, can generally deal well with statistical uncertainties, where both the alternatives and their relative probabilities are known with acceptable reliability. Some can also deal well with scenario uncertainty, where alternatives can be discerned, but not their relative probability or completeness. However, they offer few opportunities to deal effectively with ignorance and surprise (i.e. where science currently cannot provide answers), where even the alternative future developments and possible impacts are difficult to discern. Resilience-oriented/adaptive approaches offer more opportunities for tackling this level of uncertainty.

This thesis addressed how the conceptual insights from the literature applied in actual adaptation decision-situations, and what the implications were for adaptation and science-policy interaction under climate change uncertainties. The central question is: "*How do the conceptual and theoretical insights from the literature apply in the practice of climate adaptation under uncertainty; and how can uncertainty better be taken on board in climate change adaptation and interaction between science and policy on this topic?*" In order to answer this question, this dissertation describes case-studies on: (1) uncertainty in the the health impacts of climate change in the Netherlands, (2) resilience as adaptation approach for urban adaptation, (3) the role of ethics and worldviews (societal uncertainty) in the public debate on climate change in the US, (4) uncertainty communication in environmental assessments, and (5) the consequences of scientific and societal uncertainty for decision-making strategies and tools.

7.1. Scientific uncertainty in climate change impacts: Climate change & health

Chapter 2 addresses uncertainties related to health risks of climate change. Its central question is: "*What levels of uncertainty are associated with the health impacts of climate change? What does this imply for adaptation strategies?*" The present state of knowledge regarding the health risks of climate change is characterized by large knowledge gaps and deep uncertainties. As noted above, different levels of uncertainty regarding projected changes to which we will need to adapt require different designs of appropriate and targeted adaptation strategies. In a case-study on the health impacts of climate change in the Netherlands, for the first time the level of uncertainty and the factors that contribute to this situation have systematically been mapped. To this end a formal expert elicitation was carried out. Using a six-point scale, experts were asked to indicate the level of precision with which health risk estimates can be made, given the present state of knowledge.

Median scores show that for most (potential) health impacts, it is possible to indicate their sign of change, but not their magnitude. For the following health effects, the experts deemed it possible to indicate a rough order-of-magnitude: heat- and cold-related mortality, the oak processionary caterpillar, microbial contamination of swimming/recreation water, flood-related mortality and air quality-related effects. For some other effects, however, it may not be possible to even indicate the sign of change: allergic eczema, flood-related exposure to dangerous substances, wasps, UV-related weakening of the immune system, and epidemics of non-endemic vector-borne diseases (although the latter differs per specific disease). Factors that limited quantifiability include: limited available data, the multi-factorial nature of health issues, confounding factors, unknown impacts considering a high-quality health system, complex cause-effect relations leading to multi-directional impacts, possible changes of present-day response-relations, and difficulties in predicting local climate impacts.

Given this state of knowledge, the scope for 'predict & control'-type adaptation approaches seems very limited at present, for application to climate change and health. For most health effects, ignorance is the dominant level of uncertainty, and it seems more appropriate to enhance the health system's (or society's) capability of dealing with changes, uncertainties and surprises, by means of increasing resilience, flexibility, and adaptive capacity. We also recommend assessing the availability of no-regret[28] options. For those effects that can be quantified to some extent (e.g. order-of-magnitude; a combination of scenario uncertainty and ignorance), it may be useful to explore the robustness of policy strategies under a range of plausible outcomes, at least in a qualitative/semi-quantitative way. For ambiguous, yet highly relevant effects, precautionary measures could be considered. However, the flexibility of these options and risks of these creating negative side-effects or becoming and overinvestment should be assessed.

7.2. Scientific (and societal) uncertainty in adaptation practice: Resilience in climate proofing Rotterdam

Climate change may pose considerable challenges to coastal cities, particularly in low-lying urban deltas. Local climate change impacts are, however, associated with substantial uncertainties. Increasing the impacted system's resilience has been proposed as an approach that is fruitful under deep uncertainty. In chapter 3, the operationalisation of such a resilience approach is discussed for the areas outside the dike defence zones in the city of Rotterdam, the Netherlands. Its central question is: "*How can a bottom-up concept such as resilience be operationalised into potential adaptation measures in a local context?*"

Potential impacts have been explored using national climate statistics and scenarios, accounting for statistical and scenario uncertainties, and a set of 'wildcards' (imaginable surprises), accounting for ignorance & surprise. Sea level rise is expected to be a major disturbance, particularly in combination with (potential changes in) storm surge and river discharge. These can increase the flooding frequencies in these already flood-prone areas. Other relevant disturbances included increased temperature and decreased summer river discharge. These could present problems for electricity supply, drinking water supply, water quality, and air quality. Local policymakers in our study framed the impacts of disturbances as issues of societal disruption, property damage, and reduced attractiveness of the area (for residents and companies). Unclear division

[28] Options for which it is not a problem if the expected impact is not realized, or is realized to a lesser or different extent.

of responsibilities between residents, businesses, and government in regarding flood protection and property damage presently provided a feedback that could enhance such societal disruption.

Inspired on literature on stability and resilience in ecosystems, a set of six ‘resilience principles’ has been used to generate adaptation options that would enhance resilience of this urban delta: homeostasis, omnivory, high flux, flatness, buffering, redundancy. These principles (provided with description and examples) made the concept sufficiently operational for local actors to generate and explore policy options. Following analysis and comparison with similar studies, three additional principles are suggested for addressing urban resilience: foresight & preparedness/planning, compartmentalisation, and flexible planning/design. Local actors framed resilience as a highly flexible approach that is adaptive to both the changing environment and to the local situation and needs; it is more suitable and tailored to the local situation than rigid top-down regulations. Such flexibility would however require suitable formal frameworks (legal and governmental) and a different, more pro-active mentality among the local population.

The options developed using the resilience principles seems capable of coping with both statistical and scenario uncertainty. They are also expected to remain beneficial under wildcards, which were either (1) extreme forms of expected trends, or (2) opposite to the expected trends. In the latter situation, options that enhance flexibility and responsiveness were expected to perform well. It was more difficult to generate options capable of dealing with wildcards that present completely new issues (surprises not related to the expected trend). This type of wildcard would deserve extra attention; options that create flat organisation structures, short and fast communication channels, fast decision-making, and limited hierarchy could increase resilience against these surprises. Increased foresight & preparedness/planning can accomplish this as well. Concluding, a resilience approach can make a system less prone to disturbances, and enables quick and flexible responses. Including resilience in climate adaptation will make the adapted system better capable of dealing with surprises than when using traditional predictive approaches alone.

7.3. Societal uncertainty regarding climate change: Ethics and worldviews in the US public debate

Decision-making on complex issues such as climate change not only depends on the ‘physical’ side of the issue, i.e. the changes and impacts that take place, but also on various social dimensions, such as values/ethical aspects and worldviews. These relate to different perceptions of how the world works or should work (biophysically as well as in terms of social structures, processes, and procedures). These issues play an important role in international negotiations as well as national and local politics. Different perceptions regarding these aspects among stakeholders, citizens and politicians result in societal uncertainty for decision-makers. Particularly in the United States, religious groups and leaders have taken an active interest in climate change and climate policy during the past few years, highlighting its ethical dimensions. They present an interesting case in which both values and worldviews have taken the forefront of the societal debate. This case is presented in chapter 4, following the central question: "*How do differences in moral values and preferences regarding societal developments emerge in societal debate on climate change?*" This matter has been investigated using an argumentative discourse analysis of available communications of e.g. opinion documents, formal resolutions, websites, press releases, speeches, blogs, and newspaper articles of religious groups and leaders in the US.

When analyzed using a quadrant of ideal-typical worldviews (Figure 4.1; global market, global solidarity, caring region, safe region), three narratives emerged that present a particular definition of an environmental issue and shared by a group of people/organisations. Each combined two of the worldviews. 'Conservational stewardship' emphasised conserving 'God's garden' as it was created, describing mankind as part of nature, and focusing on climate change effects on nature. 'Developmental stewardship' presented a climate-sceptical discourse, which placed nature in a more serving position to mankind, emphasising turning the 'wilderness' into a 'garden', as the world should become. 'Developmental preservation' assessed that creation is good, but inherently changing, emphasising mankind's (God-given) creativity and ingenuity, concluding that progress and preservation can and should be combined. This discourse is similar to 'conservational stewardship', but presents a (comparatively) more optimistic view of mankind and technology.

All three narratives address the issue of climate change in terms of fundamental ethical questions, dealing with stewardship and social justice (interregional and intergenerational). Policy strategies that pay careful attention to the effects of climate change and climate policy on the poor – in developing nations and the US itself – may find support among the US population. Religious framings of climate change resonate with the electorates of both progressive and conservative politicians and could serve as bridging devices for bipartisan climate-policy initiatives.

The climate-sceptical discourse 'developmental stewardship' emphasises uncertainty and proposes enhancing economic and technological development in order to enhance societies' capacity to deal with environmental and other problems (for both adaptation and mitigation purposes). This relates to the 'human development approach' to climate change adaptation under uncertainty. The other two discourses often emphasise certainty. A few exceptions do address uncertainty, and argue for 'prudence', which they describe as a deliberate, reasoned basis for taking or avoiding action to achieve a moral good. This could be interpreted as a moderate and deliberative approach to the precautionary principle. It is unclear what the perception of other approaches would be, both because the debate focuses more on mitigation than adaptation, and because the literature on adaptation under uncertainty has not yet assessed the compatibility of various approaches with various worldviews. One could however hypothesise that approaches that emphasise ingenuity would find support in developmental preservation, while those that emphasise precaution would find support in conservational stewardship.

It is interesting to note virtue ethical principles (e.g. moderation, prudence, hope) were often mentioned, in each narrative. One of the literature sources discussed in the Introduction (Chapter 1) of this thesis suggests that these provide a potential way to cope with climate change uncertainties. Some sources indeed use these issues in uncertainty-related discourse, while others combine them with arguments that describe climate change as certain. Whatever their suitability for coping with scientific uncertainties, they seem to be no straightforward solution for societal uncertainties: different narratives perceive the implications very differently (e.g. what is the 'prudent' way forward?). However, from an analytical viewpoint, such differences in interpretation of the ethics of climate change, and the underlying worldviews, do offer insights into the different concerns that various groups in society may (implicitly) hold.

7.4. Dealing with uncertainty in impact assessment: Uncertainty communication in the science-policy interface

Chapter 5 focuses on the issue of communication of uncertainty information to various audiences in the science-policy interface. Its central question is: "*What does uncertainty in the knowledge presented in environmental assessments mean to policymakers and how can this uncertainty best be communicated in such assessments?*" While there are ways to address scientific uncertainties in climate change adaptation, decision-makers will need to become aware of these before such ways can be meaningfully implemented. Thus, the perceptions on, and practice of uncertainty communication is relevant for conducting climate change impact assessments. Policymakers and policy advisors participating in our study on uncertainty communication in the Environmental Balance, the Dutch yearly environmental assessment report published by PBL, differed in their perception of uncertainty. Some consider uncertainty as 'problematic but unavoidable', while others assessed that it offered opportunities as well and put the role of science in societal decision-making in perspective. The respondents mentioned above considered uncertainty communication to be a challenging, but important issue. This communication should however be concise and policy-relevant.

The policy-relevance of specific uncertainties depends on a range of factors, such as the place of an issue (e.g. an environmental issue, or a potential climate change impact) in the policy cycle, and its novelty, topicality and controversiality. Several context-specific factors enhance the policy-relevance of uncertainties: (1) when being wrong in one direction could carry more serious consequences than being wrong in the other, (2) when uncertain outcomes can have a large influence on policy advice, (3) when the value of an indicator is close to a policy goal or threshold, (4) when there is the possibility of large effects or catastrophic events, (5) in cases of societal controversy on the topic, (6) when value-laden choices in the analysis are in conflict with interests or views of stakeholders, and (7) when there is public distrust in outcomes that show low risks. Specific topics of interest include uncertainties in: (1) the environmental effects of policy, (2) whether policy goals will be met, (3) the severity of environmental problems, and (4) matters that are important for finding, selecting and prioritising policy responses. With respect to the latter, it can be important to discuss different sources and types of uncertainty and qualitative aspects of uncertainty (e.g. the 'solidity' of assumptions, methods used, and results, or dissensus among experts). This should not be only a matter of reporting 'uncertainties with implications'; it is also important to discuss these implications explicitly. Such implications could relate to, for instance, the robustness of the results, robustness of concrete policy options, or the suitability of various adaptation approaches.

There are different ways to communicate uncertainties, such as numerical data, verbal descriptions, graphics, or combinations thereof. The IPCC uses a scale of verbal descriptions for the subjective probability of various statements and conclusions in their reports. Their original term for 33-66% probability, 'medium likelihood', performed poorly when compared with respondents interpretations of this term; interpretations were widely varying, with a median of 50-75%. The more recent term 'about as likely as not', and the Environmental Balance's variant 'fifty-fifty; about 50%', performed better, with median interpretations of 40-60% probability. Respondents considered communication on the qualitative aspects of uncertainty to be important. Approaches such as a simple 'level of scientific understanding' qualifier or a more comprehensive graphical Pedigree Chart (developed for this study, see Figure 5.5 in Chapter 5), were appreciated. In addition to 'how' to communicate uncertainties, it is important to consider 'where' to communicate 'which' uncertainties. Various target groups have different information needs and different attention spans for various parts of an assessment report or communication process. It is important to progressively disclose uncertainty information throughout the communication, depending on its relevance to the target audiences of various parts of the report.

7.5. Consequences of scientific and societal uncertainty for decision-making strategies and tools: A frame-based guide

Chapter 6 presents a frame-based guide to situated decision making on climate change. Frames act as organizing principles that shape in a “hidden” and taken-for-granted way how people conceptualize an issue. The central question of this chapter is: “*How can ‘adaptation & uncertainty’ be framed in a science-policy context and what does this imply for the suitability of decision-tools?*” Scientific and societal uncertainties also have implications for the decision-making process and tools. Depending on whether beliefs about cause/effect relations (scientific uncertainty) and preferences regarding possible outcomes (societal uncertainty) are considered (un)certain or (un)disputed, four types of decision strategies can be identified. These focus on (1) computation, (2) compromise, (3) judgment, or (4) inspiration. When both cause/effect relations and preferences are certain and data are voluminous, a computational strategy, in a bureaucratic structure, can be preferred. Tools such as cost-benefit or multi-criteria analysis could be applied. When cause/effect relationships are uncertain but preferences are not, a judgemental strategy could be taken, in a collegial structure. Tools such as scenario analysis, expert elicitation, and model tools (biophysical, socio-economic, integrated) can be applied. When preferences are uncertain but beliefs about cause/effect relations are not, decision-makers may prefer a compromise strategy, in a representative structure. Tools such as negotiation and argumentation support tools and participation tools could be used. When both beliefs about cause/effect relations and outcome preferences are uncertain, the decision-making process may benefit from an inspirational strategy, in an informal structure. Cognitive aids, such as ‘rich picture’ drawings and checklists for prompting new ideas, learning-scenarios, and other creative tools may be useful.

The strategies above also relate to different frames of climate change. Decision-makers and stakeholders may interpret and frame the issue in different ways. Some may see climate change and adaptation as scientific issues that can be resolved by, for example, assessing which options are the most cost-effective. Others may consider them issues of fundamental choices, which require deliberation and negotiation. Two important contrasts in how climate change and adaptation are framed, include: (a) whether it is framed in terms of promotion (e.g. creating a climate-proof or ‘sustainable’ society, or seeing climate change as an opportunity) or prevention (e.g. preventing catastrophic impacts), and (b) whether it is framed in broad terms (e.g. long-term, conceptual/abstract, general features) or narrow terms (e.g. short-term, contextualized, specific issues or options). These issues can be loosely connected to the four strategies above (see Figure 6.1).

Explicit exposition of and deliberation on these different frames and strategies can work as an eye-opener for decision-makers, particularly where it demonstrates how to add more perspectives to the decision. As such, it may enhance the sensitivity of decision-makers to multiple interpretations of weak signals and offer some protection against 'single-action bias' (the tendency to take only one action to respond to a problem). This could make the resulting policy strategies and decisions more robust to both scientific and societal uncertainties.

7.6. Concluding remarks

Returning to the main research question, "*How do the conceptual and theoretical insights from the literature apply in the practice of climate adaptation under uncertainty; and how can uncertainty better be taken on board in climate change adaptation and interaction between science and policy on this topic?*", several concluding remarks can be made. The local impacts of climate change exhibit a mix of statistical and scenario uncertainties as well as ignorance and surprise. Not all future impacts can be meaningfully quantified or foreseen, and even for those that can, large knowledge gaps and the possibility for significant surprises remain present. Based on the case-studies in this thesis, it seems that relying solely on 'predict & control' approaches to climate change adaptation will not adequately address the challenges and complexities involved. Other approaches that are better capable of addressing deep uncertainties are necessary for successful adaptation to partially unknown future climate changes.

This does not imply that 'predict & control' approaches have no value for climate change adaptation and should be completely replaced by 'adaptive' and 'resilience-oriented' approaches. As Dessai and Van der Sluijs (2007) noted, different approaches are suitable under different levels of uncertainty. Other advantages and disadvantages of various approaches can be identified as well. For example, as the Rotterdam case has shown, approaches such as resilience can be used to adapt urban areas in the face of all three levels of uncertainty, but the effectiveness and efficiency of resilience options is very difficult to assess in quantitative terms. For 'predict & control', on the other hand, the possibility of assessing effectiveness and efficiency is a strongpoint, but at the same time this approach has the weakness that it might be based on undue certainty and potentially wrong assumptions. There may be some scope to develop scale-based scoring systems based on the resilience principles[29], but it remains to be seen to what extent these can be used meaningfully assess complex system behaviour. Predict & control and adaptive/resilience-oriented approaches can also be helpful for different management situations; e.g. resilience was framed as an approach

[29] Something similar has been done for adaptive capacity; see Gupta et al. (2010).

that is highly suitable for tailoring adaptation to the local situation, compared with more rigid prediction-oriented approaches that were implemented from national and regional levels. Other factors also influence the usefulness of various strategies; e.g. the relevance of the expected impacts, the expected encroachment on society and extensiveness of required interventions (e.g. can an approach be easily implemented in an existing situation, or would we need rigorous reforms, redevelopments, or changes in the way we 'do things'?), and the costs and co-benefits of actual options. For example, precautionary measures deal well with ignorance but can involve high costs and potential side-effects; in the health case they are advised for impacts that are both highly uncertain and highly relevant.

Furthermore, various adaptation approaches seem to appeal to different decision strategies and worldviews. Predict & control approaches, such as traditional quantitative risk approaches and scenario-based dimensioning fit well within judgemental and computational strategies and hierarchical and globally-oriented worldviews. Adaptive and resilience-oriented approaches seem better suited for compromise and inspirational strategies, and might appeal more to locally-oriented worldviews. An interesting observation in the Rotterdam case, however, is that resilience is applied within an 'economic development' frame, which links to a computational strategy. This is a risk, as stakeholders might wonder how effective the approach really is in enhancing Rotterdam's economic competitiveness, but it also shows that such couplings are far from fixed. Potentially, there is some scope to frame or implement approaches in different ways that are appealing to different worldviews.

A third point is that in any adaptation challenge, multiple levels of uncertainty may prevail at once. In the 'health' case, many potential impacts could not be quantified; 'ignorance' was the dominant level of uncertainty. For several impacts, quantification was possible, be it as a wide range and at a status of 'rough estimate of the order-of-magnitude'. Both the 'scenario-uncertainty' (the range) and 'ignorance' (the status) uncertainty levels play a large role. Both will have to be taken into account when designing an appropriate adaptation strategy. Specific policy strategies may also be designed to address an assortment of impacts, rather than a single one. If these impacts exhibit different levels of uncertainty, the final strategy will need to find a way of dealing with these multiple levels at once.

Concluding, planners, designers and policymakers in the field of climate adaptation face multiple impacts with multiple levels of uncertainty simultaneously. Even for a single effect, multiple levels of uncertainty may play a relevant role; e.g. when quantitative scenario estimates should be considered rough 'order-of-magnitude' estimates due to considerable remaining ignorance. In addition, societal uncertainties, such as worldviews and framing, are highly important for answering the question of whether particular adaptation approaches, analysis tools, and sources of scientific information will be considered relevant for the decision-situation; some are useful in a computational setting some in a inspirational setting, and others in judgemental or compromise settings (see Chapter 6). Furthermore, different perceptions regarding these issues may exist at different levels of governance (e.g. municipal versus national) and in various organizations and individuals involved. Various other factors, such as the relevance of a particular impact, also influence which adaptation approaches are seen as appropriate. Climate change adaptation under uncertainty is therefore not a matter of selecting a single particular approach depending on a single level of uncertainty. Rather, multiple approaches will need to be combined and adapted to be able to cope with multiple levels of uncertainty, multiple perceptions on the decision-situation (e.g. differences in worldview or management style between organizations involved – both in the current situation and in the future), and multiple decision-criteria.

Based on the findings of this thesis further investigation is suggested in the following areas: (a) how do the various approaches to adaptation under uncertainty relate to other decision criteria such as relevance of impacts, co-benefits, and encroachment, (b) how do the approaches relate to societal uncertainties such as values and worldviews (or can be reframed/implemented to address various worldviews), (c) what characteristics make the approaches able to cope with uncertainties[30] and can these reveal any overlaps or gaps in the way that approaches cope with uncertainty, and (d) what are the potential advantages, disadvantages, and pitfalls for various approaches (as exhibited in the case-studies/literature on these).

[30] E.g. the strategies suggested by Hallegatte (2009) seem to relate more to characteristics that allow a policy strategy to cope with uncertainty; perhaps they can be used to further analyse the policy approaches suggested by Dessai and Van der Sluijs (2007).

Hoofdstuk 7.

Samenvatting en conclusies

Klimaatvariabiliteit en –verandering zijn belangrijke factoren in de ontwikkeling van samenlevingen. Ze beïnvloeden diverse fysieke, biologische en sociale systemen. De veranderingen in de wereldgemiddelde temperatuur die de komende eeuw verwacht worden, kan een breed scala aan effecten teweeg brengen, bijvoorbeeld in de zeespiegel, neerslag, rivierafvoer, droogte, windpatronen, voedselproductie, de staat van ecosystemen, fenologie en verspreiding van soorten, en menselijke gezondheid. Het besef groeit dat aanpassing aan klimaatverandering (adaptatie) onvermijdelijk is, onder andere om impacts van klimaatverandering die de komende decennia op ons af komen het hoofd te bieden voordat het beleid om emissies van broeikasgassen terug te dringen (mitigatie) effect kan hebben. Projecties van de gevolgen van klimaatverandering gaan echter gepaard met grote onzekerheden, die opduiken (en optellen) in elke stap van dergelijke analyses. Dit geldt met name voor projecties op lokale schaal – terwijl juist deze lokale gevolgen het meest maatschappelijk relevant zijn. Dit hoge niveau van onzekerheid is een uitdaging voor de besluitvorming rond de vragen aan welke veranderingen en aan welke grootte van veranderingen we ons moeten aanpassen om de samenleving klimaatbestendig te maken. Hoe urgent, verstrekkend en flexibel zouden adaptatiemaatregelen moeten zijn?

De hoeveelheid literatuur over omgaan met klimaatonzekerheden in effectschattingen en adaptatie is zeer beperkt. Van verschillende benaderingen voor besluitvorming rond klimaatadaptatie wordt gesteld dat ze, op de een of andere manier, in staat zijn om met onzekerheden om te gaan. Voorbeelden van deze benaderingen zijn: robuuste besluitvorming, verkennend modelleren, adaptief beheer, het voorzorgsbeginsel, ‘no-regret’ benaderingen, flexibiliteit, veiligheidsmarges, ‘virtue’-ethische benaderingen, ‘backcasting’ en ‘outlier’-analyse, veerkracht, ‘anticipating design’, risicobenaderingen, traditionele scenarioanalyse, en ontwikkelings-benaderingen. Twee werkwijzen kunnen onderscheiden worden: top-down (‘voorspellen & beheersen’, ‘optimisatie’ of ‘conventioneel’) en bottom-up (‘geïntegreerd & adaptief’ of ‘veerkracht-georiënteerd’). Elk biedt handvaten om met onzekerheid om te gaan, maar ze zijn geschikt voor verschillende niveaus van onzekerheid. Zo kan ‘beheersen op basis van de beste voorspelling’ goed omgaan met statistische onzekerheden, waarbij zowel de mogelijke uitkomsten (bijv. impacts) en hun waarschijnlijkheid voldoende voorspelbaar zijn. Sommige van deze benaderingen kunnen ook goed omgaan met scenario-onzekerheden, waarbij verschillende mogelijke uitkomsten verkend kunnen worden, maar niet de waarschijnlijkheid of volledigheid hiervan. Echter, dergelijke benaderingen bieden weinig mogelijkheden om effectief om te gaan met onwetendheid (waar de wetenschap nog in het duister tast) en verrassingen, waarbij zelfs de mogelijke uitkomsten niet te voorzien zijn. Veerkracht-georiënteerde/adaptieve benaderingen bieden hiervoor meer handvaten.

Dit proefschrift verkent in welke mate de conceptuele inzichten uit de literatuur over omgaan met onzekerheid bij klimaatadaptatie toepasbaar zijn in daadwerkelijke besluitvormingssituaties, en wat de consequenties hiervan zijn voor adaptatie en wetenschaps-beleidsinteractie onder klimaatonzekerheden. De centrale vraag hierbij is: "*Hoe toepasbaar zijn de conceptuele en theoretische inzichten in de literatuur in de praktijk van klimaatadaptatie onder onzekerheid; en hoe kan onzekerheid beter meegenomen worden in klimaatadaptatiebeleid en in de interactie tussen wetenschap en beleid rond dit vraagstuk?*" Om een antwoord te geven op deze vraag worden in dit proefschrift case-studies beschreven naar: (1) onzekerheid in gezondheidsimpacts van klimaatverandering in Nederland, (2) veerkracht als adaptatiebenadering voor onzekere klimaatverandering in stedelijk gebied, (3) de rol van ethiek en wereldbeelden (maatschappelijke onzekerheden) in het maatschappelijk debat rond klimaatverandering in de VS, (4) onzekerheidscommunicatie in effectrapportages, en (5) de consequenties van wetenschappelijke en maatschappelijke onzekerheid voor besluitvormingsstrategieën en –tools.

7.1. Wetenschappelijke onzekerheid in klimaatimpacts: klimaatverandering en gezondheid

Hoofdstuk 2 onderzoekt onzekerheden rond klimaatverandering en gezondheid. De centrale vraag is: "*Welke onzekerheidsniveaus spelen bij de gezondheidsimpacts van klimaatverandering? Wat betekent dit voor adaptatiestrategieën?*" De huidige stand van kennis rond dit onderwerp wordt gekarakteriseerd door grote kennislacunes en grote onzekerheden. Verschillende onzekerheidsniveaus rond de verwachte veranderingen waaraan men zich moet aanpassen, vereisen een verschillende opzet van adaptatiestrategieën. In de casus (over Nederland) zijn deze niveaus voor het eerst systematisch in kaart gebracht, middels expertbevraging. Aan experts is gevraagd om op een zespunts-schaal het niveau van precisie aan te geven waarmee schattingen van de gezondheidsrisico's gemaakt kunnen worden, gegeven de huidige stand van kennis.

Uit de mediaan van de scores blijkt dat het voor de meeste (potentiële) impacts mogelijk is om de richting van de veranderingen aan te geven, maar niet de grootte ervan. Voor de volgende effecten meenden de experts dat het mogelijk is om een ruwe schatting van de ordegrootte te geven: hitte- en koudegerelateerde sterfte, de eikenprocessierups, microbiële besmetting van zwem/recreatie water, overstromingsgerelateerde sterfte en effecten via luchtkwaliteit. Voor enkele andere effecten is het echter niet mogelijk om zelfs de richting van veranderingen aan te geven (ambigu): allergisch eczeem, overstromingsgerelateerde blootstelling aan gevaarlijke stoffen, wespen, UV-gerelateerde verzwakking van het immuunsysteem en epidemieën van niet-endemische vectorgebonden ziekten (al verschilt dit per ziekte). Factoren die kwantificeren bemoeilijken zijn: beperkte beschikbare data, multifactorialiteit van gezondheidskwesties, verstorende variabelen (counfounders), onbekende impacts gezien het goede gezondheidssysteem, complexe oorzaak-gevolg relaties leidend tot multi-directionele impacts, mogelijke veranderingen van huidige response-relaties, en moeilijkheden in het voorspellen van lokale impacts.

Gezien deze staat van kennis, lijkt de toepasbaarheid van 'beheersen op basis van de beste voorspelling'-type adaptatiebenaderingen voor klimaat en gezondheid op dit moment erg beperkt. Bij de meeste gezondheidseffecten is onwetendheid het dominante onzekerheidsniveau. Het versterken van de capaciteit van het gezondheidssysteem (of de samenleving) om met veranderingen, onzekerheden en verrassingen om te gaan, door de veerkracht, flexibiliteit en adaptieve capaciteit te vergroten, lijkt daarom een geschiktere aanpak. We raden ook aan na te gaan hoeveel en welke mogelijke no-regret[31] opties er zijn. Voor effecten die tot op zekere hoogte te kwantificeren zijn (bijv. als ordegrootte; een combinatie van scenario-onzekerheid en onwetendheid), adviseren we om de robuustheid van beleidsstrategieën te onderzoeken voor een spectrum aan plausibele veranderingen. Voor ambigue, maar zeer relevante effecten zouden maatregelen binnen het voorzorgsprincipe overwogen kunnen worden. Hierbij is het verstandig om de flexibiliteit en risico's op negatieve neveneffecten of overinvesteringen na te gaan.

7.2. Wetenschappelijke (en maatschappelijke) onzekerheid: Veerkracht en klimaatbestendig Rotterdam

Klimaatverandering kan aanzienlijke uitdagingen opleveren voor kuststeden, vooral in laaggelegen stedelijke delta's. De onzekerheden rond lokale impacts zijn echter substantieel. Een mogelijk nuttige adaptatiebenadering onder grote onzekerheden is het vergroten van de veerkracht van het systeem dat getroffen wordt door klimaatveranderingen. In hoofdstuk 3 wordt het operationaliseren van zo'n veerkrachtbenadering bestudeerd voor de buitendijkse bebouwde gebieden in Rotterdam. De centrale vraag is: "*Hoe kan een bottom-up concept als veerkracht geoperationaliseerd worden in potentiële lokale adaptatieopties?*"

Mogelijke impacts van klimaatverandering zijn verkend aan de hand van nationale klimaatstatistieken en –scenario's, inclusief statistische en scenario-onzekerheden. Een set van 'wildcards' (voorstelbare verrassingen) is gebruikt om onwetendheid mee te nemen in de analyse. Zeespiegelstijging wordt naar verwachting een belangrijke verstoring voor dit gebied, met name in combinatie met (mogelijke veranderingen in) stormvloed en rivierafvoer. Deze kunnen leiden tot verhoging van de overstromingsfrequenties in deze toch al overstromingsgevoelige gebieden. Andere relevante verstoringen zijn hogere temperaturen en lagere rivierafvoer in de zomer. Deze kunnen problemen opleveren voor de energie- en drinkwatervoorziening en

[31] Opties waarbij het niet erg is als het verwachte probleem waartegen ze gericht zijn zich niet, of in mindere of andere mate, voordoet.

water- en luchtkwaliteit. Lokale beleidsmakers in ons onderzoek beschreven de impacts van deze verstoringen als kwesties van maatschappelijke ontwrichting, materiële schade, en aantasting van aantrekkelijkheid van het gebied (voor bewoners en bedrijven). Onduidelijke verdeling van verantwoordelijkheden tussen bewoners, bedrijven en overheid op het gebied overstromingsbescherming en vergoeding van overstromingsschade kan op dit moment dergelijke verstoringen versterken.

Een set van zes ‘veerkrachtprincipes’, geïnspireerd op de literatuur rond stabiliteit en veerkracht in ecosystemen, is gebruikt om adaptatieopties te genereren die de veerkracht van deze stedelijke delta kunnen versterken. De principes (met omschrijving en voorbeelden) maakten het concept voldoende operationeel voor lokale actoren om opties te genereren en verkennen. Na een vergelijking van de resultaten met die van andere studies zijn drie nieuwe principes toegevoegd voor veerkracht van stedelijk gebied: (1) toekomstverkenning & voorbereiding/planning, (2) compartimentalisatie en (3) flexibele planning en ontwerp. Locale actoren beschreven in ons onderzoek veerkracht als een zeer flexibele benadering die adaptief is aan zowel de veranderende omgeving als specifieke lokale situaties en behoeften. Het is hierin bruikbaarder en beter toespitsbaar op de lokale situatie dan rigide top-down regulering. Deze flexibiliteit vereist echter wel bruikbare formele raamwerken (juridisch en gouvernementeel) en een andere, meer proactieve houding bij de lokale bevolking.

De set opties die gegenereerd is met behulp van de veerkrachtprincipes lijkt bestand tegen zowel statistische als scenario-onzekerheid. Ook blijven deze opties naar verwachting nuttig onder wildcards, met als effect ofwel (1) extreme vormen van verwachte trends of (2) het tegenovergestelde van verwachte trends. In het laatste geval zouden vooral opties die de flexibiliteit en responsiviteit vergroten nuttig kunnen blijken. Het was lastiger om adaptatieopties te bedenken die bestand zijn tegen wildcards die compleet nieuwe ontwikkelingen presenteren (bijv. het verschijnen van een nieuwe ziekte). Dit type wildcard vraagt extra aandacht in de analyse: opties die zorgen voor een platte organisatiestructuur, korte en snelle communicatiekanalen, snelle besluitvorming, en weinig hiërarchie zouden de veerkracht kunnen versterken. Toekomstverkenning en voorbereiding/planning kunnen hier eveneens voor zorgen. . Een veerkrachtbenadering kan een systeem minder kwetsbaar maken voor verstoringen en geeft de mogelijkheid om snel en flexibel te reageren. Meenemen van veerkracht in klimaatadaptatie stelt het aangepaste systeem beter in staat om met verrassingen om te gaan dan wanneer alleen traditionele voorspellingsbenaderingen gebruikt worden.

7.3. Maatschappelijke onzekerheid rond klimaat: Ethiek en wereldbeelden in het publieke debat in de VS

Besluitvorming rond complexe kwesties als klimaatverandering hangt niet alleen af van de 'fysieke' kant ervan, zoals de veranderingen en impacts die plaatsvinden, maar ook van diverse maatschappelijke dimensies, zoals waarden en ethische aspecten en wereldbeelden. Die houden verband met verschillende visies op hoe de wereld werkt of zou moeten werken (biofysisch, maar ook in termen van maatschappelijke structuren, processen, procedures). Dit is belangrijk in internationale onderhandelingen, maar ook in nationale en lokale politiek. Verschillende visies op deze aspecten onder stakeholders, burgers en politici resulteren in maatschappelijke onzekerheid voor de besluitvormers. In de Verenigde Staten waar religie en politiek dicht verweven zijn hebben religieuze groepen en leiders aandacht gekregen voor klimaatverandering en -beleid, waarbij ze nadruk leggen op de ethische aspecten. Het is daarmee een interessante casus waarin waarden als wereldbeelden op de voorgrond staan in het maatschappelijk debat. In hoofdstuk 4 wordt de casus gepresenteerd, met als vraag "*Hoe komen verschillen in morele waarden en -voorkeuren ten aanzien van maatschappelijke ontwikkelingen naar voren in het maatschappelijk debat rond klimaatverandering?*" Dit is onderzocht middels een argumentatieve discoursanalyse van o.a. opiniedocumenten, formele resoluties, websites, persverklaringen, speeches, blogs en krantenartikelen van religieuze groepen en leiders in de VS.

Een analyse aan de hand van een kwadrant met ideaal-typische wereldbeelden (Figuur 4.1; mondiale markt, mondiale solidariteit, zorgzame regio, veilige regio) resulteerde in drie perspectieven (narratives), die elk een bepaalde kijk geven op het onderwerp die gedeeld wordt door een groep mensen/organisaties. Elk combineerde twee van de wereldbeelden. 'Bewarend rentmeesterschap' benadrukte het bewaren van 'Gods tuin' zoals deze geschapen was, beschreef de mensheid als deel van de natuur en richtte zich vooral op effecten van klimaatverandering op de natuur. 'Ontwikkelend rentmeesterschap' daarentegen presenteerde een klimaatsceptisch discour, waarbij de natuur dienend werd gezien aan de mens, benadrukkend dat de 'wildernis' in een 'tuin' veranderd moest worden. 'Ontwikkelend behouden' stelde dat de schepping goed is, maar inherent veranderend, waarbij de (door God gegeven) menselijke creativiteit en inventiviteit werd benadrukt; ontwikkeling en conservatie kunnen en moeten gecombineerd worden. Dit discours is vergelijkbaar met 'bewarend rentmeesterschap', maar heeft een (naar verhouding) optimistischer beeld van de mensheid en technologie.

Alle drie de perspectieven beschreven klimaatverandering in termen van fundamentele ethische vragen rond rentmeesterschap en sociale rechtvaardigheid (interregionaal en intergenerationeel). Beleidsstrategieën die zorgvuldig rekening houden met de effecten van klimaatverandering en klimaatbeleid op de armen, zowel in ontwikkelingslanden als de VS zelf, kunnen mogelijk draagvlak krijgen onder de populatie in de VS. Religieuze framing van klimaatverandering resoneert bij het electoraat van zowel progressieve en conservatieve politici en zou een brugfunctie kunnen vervullen voor breedgedragen initiatieven voor klimaatbeleid.

Het klimaatsceptische 'ontwikkelend rentmeesterschap' benadrukte onzekerheid en stelde voor om economische en technologische ontwikkeling te stimuleren, om zo de capaciteit om met milieu- en overige problemen om te gaan te vergroten. Dit relateert aan de 'ontwikkelingsbenadering' van klimaatadaptatie onder onzekerheid. De andere twee discoursen benadrukten vaak zekerheid. Enkele uitzonderingen hadden het wel over onzekerheid en stelden 'prudentie' voorop. Dit beschreven ze als een bewuste, beredeneerde basis voor het wel of niet nemen van maatregelen om een moreel goed te bewerkstelligen. Dit zou geïnterpreteerd kunnen worden als een soort gematigde en deliberatieve benadering van het voorzorgsprincipe. Het is onduidelijk wat de kijk op andere adaptatiebenaderingen zou zijn, zowel omdat het debat vooral over mitigatie gaat als omdat in de literatuur rond klimaatadaptatie onder onzekerheid nog geen verkenningen bestaan van de compatibiliteit van benaderingen met verschillende wereldbeelden. Een hypothese zou kunnen zijn dat benaderingen die inventiviteit benadrukken goed zouden vallen binnen 'ontwikkelend bewaren', terwijl degenen die voorzichtigheid benadrukken passen binnen 'bewarend rentmeesterschap'.

Het is interessant dat 'deugd'-ethische principes (bijv. moderatie, prudentie, hoop) vaak genoemd werden, in elk perspectief. Een van de in de Introductie (H.1) genoemde literatuurbronnen stelt dat dergelijke principes helpen om met klimaatonzekerheden om te gaan. Enkele bronnen gebruikten deze inderdaad voor onzekerheidsdiscours, terwijl anderen het combineerden met argumenten die klimaatverandering als 'zeker' beschreven. Hun nut voor het omgaan met wetenschappelijke onzekerheden daargelaten, lijkt het dat ze geen eenduidige oplossing bieden voor maatschappelijke onzekerheid: de verschillende perspectieven presenteerden een zeer verschillend beeld van implicaties ervan (bijv. wat is een prudente aanpak?). Echter, vanuit analytisch oogpunt geven deze verschillen in interpretatie van de ethische aspecten en onderliggende wereldbeelden wel inzicht in de verschillende zorgen die (impliciet) leven onder diverse maatschappelijke groepen.

7.4. Onzekerheid in effectanalyses: Onzekerheids-communicatie in de wetenschap-beleid interface

Hoofdstuk 5 richt zich op het communiceren van onzekere informatie naar diverse doelgroepen in de wetenschap-beleid interface. De centrale vraag is: "*Wat betekent onzekerheid in de kennis die in milieu-assessments gepresenteerd wordt voor beleidsmakers en hoe kan deze onzekerheid het best gecommuniceerd worden in dergelijke milieu-assessments?*" Er zijn weliswaar manieren om met wetenschappelijke onzekerheden om te gaan in klimaatadaptatie, maar besluitvormers moeten zich wel bewust zijn van deze onzekerheden voordat dit op een zinvolle manier gedaan kan worden. De visies op, en praktijk van onzekerheidscommunicatie is daarom relevant voor het uitvoeren van impact assessments (effectschattingen) van klimaatverandering. Beleidsmakers en beleidsadviseurs die in het kader van ons onderzoek deelnamen aan een serie workshops over onzekerheidscommunicatie in de Milieubalans die jaarlijks door het PBL in Nederland wordt gepubliceerd, verschilden in hun perceptie van onzekerheid. Sommigen zien onzekerheid als 'problematisch maar niet te voorkomen'; anderen menen dat het kansen creëert en de rol van wetenschap in maatschappelijke besluitvorming in perspectief zet. De betreffende deelnemers zagen onzekerheidscommunicatie als uitdagend, maar belangrijk. Deze communicatie moet echter wel beknopt en beleidsrelevant zijn.

De beleidsrelevantie van specifieke onzekerheden hangt af van diverse factoren, zoals de plaats van een kwestie in de beleidscyclus en de 'nieuwheid', nieuwswaardigheid en controversialiteit ervan. Een aantal contextspecifieke factoren versterkt de beleidsrelevantie: (1) wanneer een fout in de ene richting ingrijpender gevolgen heeft dan in de andere richting, (2) wanneer onzekere uitkomsten grote invloed hebben op het beleidsadvies, (3) wanneer de waarde van een indicator dichtbij het beleidsdoel of een drempelwaarde ligt, (4) wanneer er kans is op grote effecten of catastrofes, (5) bij controversiële onderwerpen , (6) wanneer waardegeladen keuzes in analyses conflicteren met de belangen of visies van stakeholders, en (7) wanneer er publiek wantrouwen heerst tegen resultaten die een klein risico aangeven. Specifieke onderwerpen die interessant gevonden worden blijken: (1) de milieueffecten van beleidsinspanningen, (2) of beleidsdoelen gehaald worden, (3) de ernst van milieuproblemen, en (4) kwesties die belangrijk zijn voor het vinden, selecteren en prioriteren van beleidsacties. Voor dit laatste kan het belangrijk zijn om in te gaan op verschillende bronnen en typen van onzekerheid en kwalitatieve aspecten van onzekerheid (bijv. de 'hardheid' van aannames, gebruikte methoden en resultaten). Dit moet echter niet blijven bij het aanreiken van 'onzekerheden met implicaties'; het is ook van belang om deze implicaties expliciet te bespreken. Die implicaties kunnen gaan om bijvoorbeeld de robuustheid van de resultaten, de robuustheid van concrete beleidsopties, of de bruikbaarheid van verschillende adaptatiebenaderingen.

Er zijn verschillende manieren om onzekerheden te communiceren, zoals numerieke data, verbale beschrijvingen, figuren, of combinaties daarvan. De IPCC gebruikt een schaal van verbale beschrijvingen van de subjectieve waarschijnlijkheid van diverse conclusies en uitspraken in hun rapportages. Hun originele term voor 33-66% waarschijnlijkheid, 'middelgrote waarschijnlijkheid', werkte slecht: interpretaties van respondenten liepen breed uiteen, met een mediaan van 50-75%. De meer recente term 'ongeveer even waarschijnlijk als onwaarschijnlijk' en de Milieubalans-term 'fifty-fifty; ongeveer 50%' deden het beter, met mediane interpretaties van 40-60%. Respondenten waardeerden manieren om kwalitatieve onzekerheden te communiceren, zoals een simpele kwalificatie van het 'niveau van wetenschappelijk begrip' en de meer uitgebreide grafische Pedigree Chart (ontwikkeld voor deze studie, zie figuur

5.5). Naast 'hoe' onzekerheden te communiceren, is het ook belangrijk om na te gaan 'welke' onzekerheden gecommuniceerd moeten worden. Diverse doelgroepen hebben verschillende informatiebehoeften en verschillende hoeveelheden aandacht voor verschillende gedeelten van een rapport of communicatieproces. Het is belangrijk om onzekerheidsinformatie geleidelijk te ontsluiten, afhankelijk van de relevantie ervan voor verschillende de doelgroepen.

7.5. Gevolgen van onzekerheid voor besluitvormings-strategieën en -tools

Hoofdstuk 6 behandelt besluitvorming over klimaatverandering in de context van 'frames'. Frames fungeren als organiserende principes die, op een 'verborgen' en als vanzelfsprekend geziene manier, bepalen hoe mensen een kwestie conceptualiseren. De centrale vraag is: "*Hoe kan 'adaptatie & onzekerheid" geframed worden in een wetenschap-beleid context en wat betekent dit voor de bruikbaarheid van verschillende besluitvormingstools?*". Wetenschappelijke en maatschappelijke onzekerheden hebben consequenties voor het besluitvormingsproces en de tools/hulpmiddelen die hierin gebruikt worden. Afhankelijk van of de oorzaak-gevolg relaties (wetenschappelijke onzekerheid) en voorkeuren voor mogelijke uitkomsten (maatschappelijke onzekerheid) als (on)zeker of (on)betwist worden gezien, kunnen vier type besluitvormingsstrategieën onderscheiden worden. Deze richten zich op: (1) berekening, (2) compromissen, (3) beoordeling, of (4) inspiratie. Wanneer zowel oorzaak-gevolg relaties als maatschappelijke voorkeuren zeker/onbetwist zijn en er ruim voldoende gegevens zijn, kan de voorkeur uitgaan naar een berekeningsstrategie, in een bureaucratische structuur. Hierbij kunnen tools als kosten-baten analyse of multicriteria analyse gebruikt worden. Wanneer oorzaak-gevolg relaties onzeker zijn, maar de voorkeuren eenduidig, kan een beoordelingsstrategie toegepast worden, in een collegiale structuur. Tools als scenarioanalyse, expertbevraging en modelleertools (biofysisch, socio-economisch, geïntegreerd) kunnen hierbij gebruikt worden. Wanneer de voorkeuren onzeker/betwist zijn, maar de oorzaak-gevolgrelaties niet, dan kan een compromisgeoriënteerde strategie gehanteerd worden, in een representatieve structuur. Nuttige tools hierbij zijn bijvoorbeeld onderhandelings- en argumentatietools en participatieve tools. Wanneer zowel oorzaak-gevolg relaties en voorkeuren onzeker/betwist zijn, is kan de besluitvorming voordeel hebben bij een inspiratiegeoriënteerde strategie, in een informele structuur. Hierbij zijn 'cognitieve hulpmiddelen', zoals 'rich picture' tekeningen en checklists die het genereren van nieuwe ideeën stimuleren, leer-scenario's en andere creatieve hulpmiddelen nuttig.

De bovenstaande strategieën hebben ook betrekking op diverse 'frames' van klimaatverandering. Besluitvormers en actoren kunnen een kwestie op verschillende manieren framen en interpreteren. Bijvoorbeeld: sommigen kunnen klimaatverandering en adaptatie zien als ‘wetenschappelijk probleem’, wat aangepakt kan worden door simpelweg te analyseren welke beleidsopties het meest kosteneffectief zijn. Anderen daarentegen kunnen het zien als een kwesties die vragen om fundamentele keuzes, die om deliberatie en onderhandeling vragen. Twee belangrijke contrasten in hoe klimaatadaptatie geframed kan worden, zijn: (a) of het geframed wordt in termen van promotie (bijv. creëren van een klimaatbestendige of duurzame samenleving, of klimaatverandering zien als ‘kans’) of preventie (bijv. voorkomen van catastrofale gevolgen); en (b) of het geframed wordt in brede/algemene termen (bijv. lange termijn, conceptueel/abstract, algemene eigenschappen) of smalle/specifieke termen (bijv. korte termijn, in specifieke context, en specifieke problemen of oplossingen). Deze zijn losjes te verbinden met de vier bovengenoemde strategieën (zie figuur 6.1).

Expliciete expositie en deliberatie rond deze verschillende frames en strategieën kan een ‘eye-opener’ zijn voor besluitvormers, met name wanneer het laat zien hoe er meer perspectieven bij de beslissing betrokken kunnen worden. Het kan zo de gevoeligheid van besluitvormers voor meerdere interpretaties van ‘zwakke signalen’ (‘weak signals’) versterken en enige weerstand bieden tegen ‘single-action bias’ (de neiging om slechts één actie te nemen om een probleem tegen te gaan). Dit kan de uiteindelijke beleidsstrategieën en beslissingen robuuster maken voor zowel wetenschappelijke als maatschappelijke onzekerheden.

7.6. Concluderende opmerkingen

Terugkerend naar de hoofdvraag, “*Hoe toepasbaar zijn de conceptuele inzichten in de literatuur in de praktijk van klimaatadaptatie onder onzekerheid; en hoe kan onzekerheid beter meegenomen worden in klimaatadaptatiebeleid en in de interactie tussen wetenschap en beleid rond dit vraagstuk?*”, kunnen enkele concluderende opmerkingen gemaakt worden. De lokale gevolgen van klimaatverandering vertonen een mix van statistische en scenario-onzekerheden en onwetendheid & verrassing. Niet alle toekomstige impacts kunnen op een zinvolle manier gekwantificeerd of voorzien worden en zelfs voor degenen waarbij dat wel kan, blijven grote kennisleemtes en mogelijke significante verrassingen aanwezig. Kijkend naar de casestudies in dit proefschrift, lijkt het dat vertrouwen op alleen ‘beheersen op basis van de beste voorspelling’ als adaptatiebenadering onvoldoende is om de uitdagingen en complexiteiten af te dekken. Andere benaderingen, die beter om kunnen gaan met grote onzekerheden, zijn nodig om succesvolle aanpassing aan deels onbekende toekomstige klimaatveranderingen te bevorderen.

Dit betekent niet dat ‘beheersen op basis van de beste voorspelling’ geen nut heeft voor klimaatadaptatie en volledig zou moeten worden vervangen door ‘adaptieve’ en ‘veerkrachtgeoriënteerde’ benaderingen. Zoals Dessai en Van der Sluijs (2007) opmerken, hangt de bruikbaarheid van verschillende adaptatiebenaderingen af van het niveau van onzekerheid. Andere voor- en nadelen van adaptatiebenaderingen kunnen ook aangegeven worden. Zoals de Rotterdam-casus liet zien, kunnen benaderingen als veerkracht weliswaar gebruikt worden om je aan te passen aan klimaatverandering onder verschillende niveaus van onzekerheid, maar is het erg lastig om de effectiviteit en efficiëntie van veerkrachtopties te bepalen. Voor de benadering 'beheersen op basis van de beste voorspelling' is het wel mogelijk om effectiviteit en efficiëntie te bepalen, maar deze benadering heeft als zwakte dat de adaptatie gebaseerd is op onterecht aangenomen zekerheid en mogelijk verkeerde aannames. Het is voor veerkracht wellicht mogelijk om een soort score-systeem (schaal) te maken, gebaseerd op de veerkrachtprincipes[32], maar het is onduidelijk of zo'n schaal bruikbaar is voor het bepalen van het gedrag van complexe systemen. 'Beheersen op basis van de beste voorspelling' en adaptieve/veerkrachtgeoriënteerde benaderingen kunnen ook nuttig zijn in verschillende managementsituaties. Veerkracht werd bijvoorbeeld geframed als een benadering die zeer geschikt is om adaptatie op maat te maken voor de lokale situatie, waar meer rigide voorspellingsgerichte benaderingen op nationaal en regionaal niveau werden toegepast. Andere factoren zijn ook relevant voor de bruikbaarheid van diverse strategieën; bijv. relevantie van verwachte impacts, de verwachte (maatschappelijke) ingrijpendheid van beleidsopties en kosten en nevenvoordelen van maatregelen. Bijvoorbeeld: voorzorg werkt goed bij onwetendheid, maar kan hoge kosten en neveneffecten inhouden. In de gezondheidscasus werden voorzorgsmaatregelen geadviseerd voor impacts die zowel zeer onzeker als zeer relevant zijn.

Daarnaast lijken de verschillende adaptatiebenaderingen interessant binnen verschillende besluitvormingsstrategieën en wereldbeelden. Benaderingen gericht op 'beheersen op basis van de beste voorspelling', zoals traditionele kwantitatieve risicobenaderingen en scenariogebaseerd dimensioneren passen goed bij beoordelende en berekenende beleidsstrategieën en hiërarchische en globaal-georiënteerde wereldbeelden. Adaptieve en veerkracht-georiënteerde passen beter bij compromis- en inspiratiestrategieën en lokaal-georiënteerde wereldbeelden. Het is interessant dat veerkracht in de Rotterdam-casus werd toegepast binnen een 'economische ontwikkeling'-frame, dat gekoppeld is aan de berekenende strategie. Dit is een risico: actoren kunnen zich afvragen hoe effectief de benadering is in het versterken van het concurrentievermogen van Rotterdam. Echter, het laat ook zien dat dergelijke koppelingen zeker niet vaststaan. De adaptatiebenaderingen kunnen waarschijnlijk zo geframed of geïmplementeerd worden dat ze beter passen bij diverse wereldbeelden.

Een derde punt is dat bij een adaptatieopgave meerdere niveaus van onzekerheid tegelijkertijd kunnen spelen. In de gezondheidscasus bleek dat de meeste impacts niet gekwantificeerd kunnen worden: onzekerheidsniveau 'onwetendheid' overheerst hier. Voor enkele impacts is kwantificering wel mogelijk, zij het als een

[32] Iets dergelijks is ook voorgesteld voor adaptieve capaciteit; zie Gupta et al. (2010).

brede range en een status van ‘ruwe schatting van de ordegrootte’. Zowel onzekerheidsniveau ‘scenario-onzekerheid’ (de range) als ‘onwetendheid’ (de status) spelen hier een belangrijke rol. Bij het kiezen van de beleidsaanpak zal met beiden rekening gehouden moeten worden. Daarnaast kunnen specifieke beleidsstrategieën ontworpen worden om een spectrum van impacts aan te pakken, in plaats van slechts een. Als deze impacts meerdere niveaus van onzekerheid hebben, moet de uiteindelijke strategie met deze meerdere niveaus kunnen omgaan.

Concluderend kan gesteld worden dat planvormers, ontwerpers en beleidsmakers op het gebied van klimaatadaptatie te maken krijgen met meerdere impacts en meerdere onzekerheidsniveaus tegelijkertijd. Daarnaast zijn maatschappelijke onzekerheden, zoals verschillende wereldbeelden, erg belangrijk voor het antwoord op de vraag of een adaptatieoptie, analysetool of wetenschappelijke informatiebron als relevant zal worden gezien voor de beslissing; sommige zijn nuttig in berekeningssituaties, anderen in inspiratiesituaties, en weer anderen in beoordelings- of compromissituaties (zie Hoofdstuk 6). Daarnaast kunnen op verschillende overheidsniveaus (bijv. gemeentelijk versus nationaal) verschillende visies op deze situatie aanwezig zijn. Hetzelfde geldt voor verschillende betrokken organisaties en individuen. Diverse andere factoren, zoals de relevantie van een impact, beïnvloeden eveneens of een adaptatiebenadering als ‘passend’ zal worden ervaren. Klimaatadaptatie onder onzekerheid is dus niet slechts een kwestie van het selecteren van één enkele benadering, gekoppeld aan één enkel onzekerheidsniveau. Meerdere benaderingen zullen gecombineerd moeten worden om met meerdere onzekerheidsniveaus, percepties op de beslissingssituatie (bijv. wereldbeelden en managementstijlen), en besluitvormingscriteria om te kunnen gaan.

Gebaseerd op de bevindingen van dit proefschrift is het aan te raden om nader te kijken naar de volgende kwesties: (a) hoe relateren de diverse adaptatiebenaderingen onder onzekerheid aan andere besluitvormingscriteria als relevantie van impacts, nevenvoordelen en ingrijpendheid, (b) hoe relateren ze aan maatschappelijke onzekerheden als waarden en wereldbeelden (of: hoe kunnen ze anders geframed of geïmplementeerd worden om hieraan te linken), (c) welke karakteristieken stellen de benaderingen in staat om om te gaan met onzekerheden[33] en laten die enige overlap of leemtes zien in de manier waarop ze met onzekerheid omgaan, en (d) wat zijn de mogelijke voor- en nadelen en valkuilen van verschillende benaderingen (zoals ze naar voren komen in de casestudies en literatuur hierover)?

[33] Bijv. de suggesties in Hallegatte (2009) lijken meer verband te houden met karakteristieken die een beleidsstrategie in staat stellen om om te gaan met onzekerheid. Wellicht kunnen ze gebruikt worden om de benaderingen van Dessai en Van der Sluijs (2007) verder te analyseren.

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Curriculum Vitae

Arjan Wardekker (Amersfoort, 5 September 1981) studied Chemistry at Utrecht University (BSc.-equiv. 2003, MSc. 2005) and graduated within the MSc. programme Natural Resources Management. He completed three professional internships: at Utrecht University Museum (science communication & education), at UU department of Science Education (risk communication on chemical safety & health risks), and a final internship and secondary MSc. thesis at De Natuurkalender (climate change, air quality & public health, focusing on hay fever), based at the Foundation for Sustainable Development and Wageningen University. During his studies, he also worked as a science editor/writer on chemistry & environment at 'Magazijn', the magazine of the Utrecht Science Shops, and as a research assistant at the UU Copernicus Institute.

In 2005, Arjan started working life as Researcher Environmental Risk Management, at the department of Science, Technology and Society at Utrecht University. He contributed to various research and advisory projects on a colourful mix of topics, involving both natural and social sciences. Major fields included: uncertainty, climate change, environment & health, and methodology & tools for environmental assessment & science-policy interaction. During 2006-2007, he briefly left the UU for a thirteen-month position as Methodology Advisor & Researcher at the Netherlands Environmental Assessment Agency.

Publications:

Scientific journal articles

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