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

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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.


## 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

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'deep' uncertainties and limits to its quantification is central in several fields which 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., 2008). 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, 2007) 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 Rinnooij (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.[1] 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 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

[1] 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.

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, 2005). 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 (Sections 3 and 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).

## 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 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.

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 all people to whom the MNP had distributed a

**Table 1 – Overview of research setup**

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

copy of the Environmental Balance 2005 ($n \approx 3000$). 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 h 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).

## 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 Fig. 1) (Wardekker et al., 2008). 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 ($\chi^2$ 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

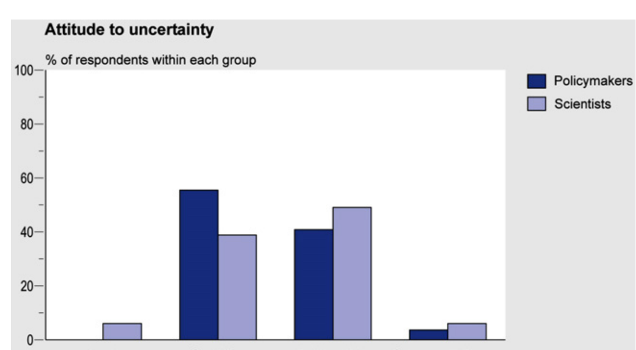


**Fig. 1 – Attitudes towards uncertainty ($n = 118$). Source: Wardekker et al. (2008).**

the workshops and survey ($n = 65$) the ratio was roughly 3:1 in favour of ''Quantify''.

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,[2] 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.

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

## 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.

### 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[3] 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.

### 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.

### 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.

### 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 Fig. 2). The effect of the recalculations of these data is of the same order of magnitude as the 2002 $2\sigma$ 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.

[3] The precautionary principle (e.g. 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.

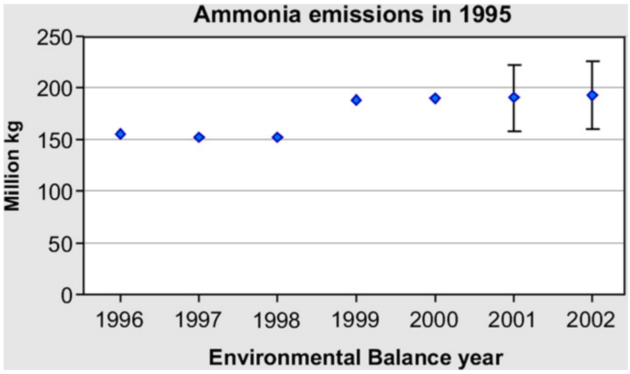


**Fig. 2 – Dutch ammonia emissions in 1995, as reported in different Environmental Balances. Error bars indicate 2$\sigma$ intervals (technical uncertainty, first reported in 2001). Source: Honingh (2004).**

## 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.

### 5.1. *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, its 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, 2007). 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 Fig. 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.

### 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

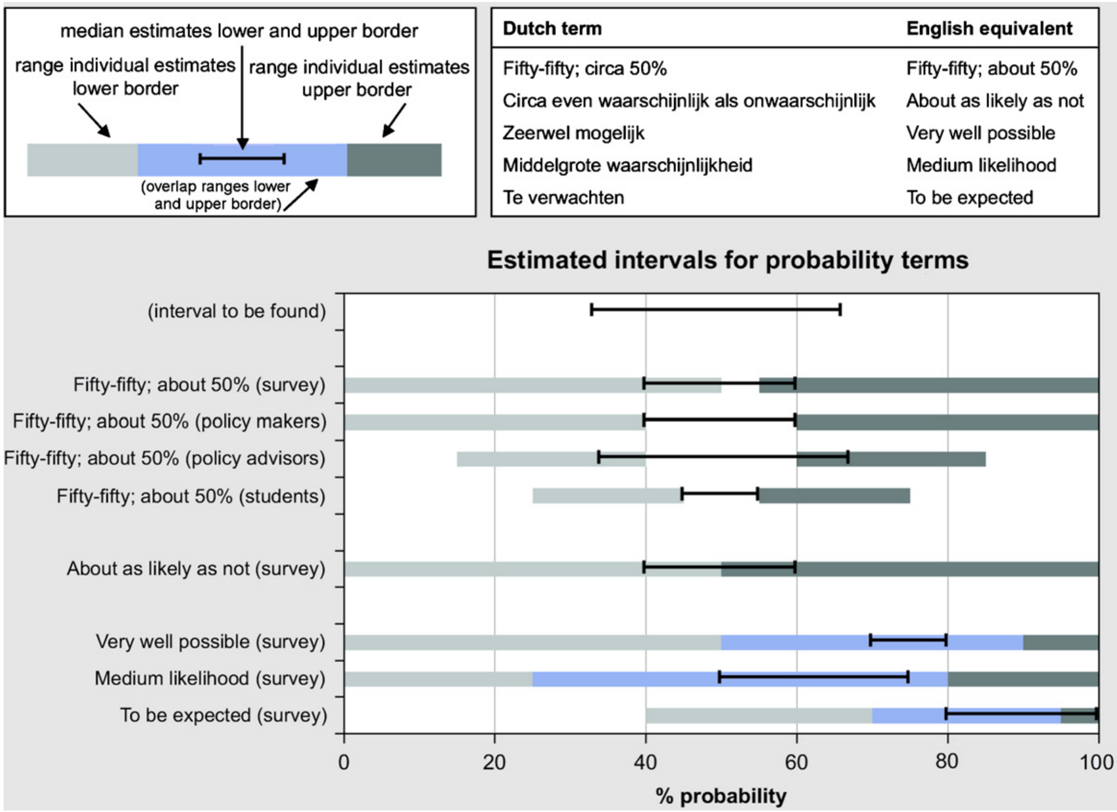


**Fig. 3 – Estimated probability intervals (. . .% to . . .%) for "medium likelihood" probability terms.**

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. Fig. 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. Fig. 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.

### 5.3. *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.

One verbal approach to communicate qualitative aspects is to add a level-of-knowledge indicator. The wording in the

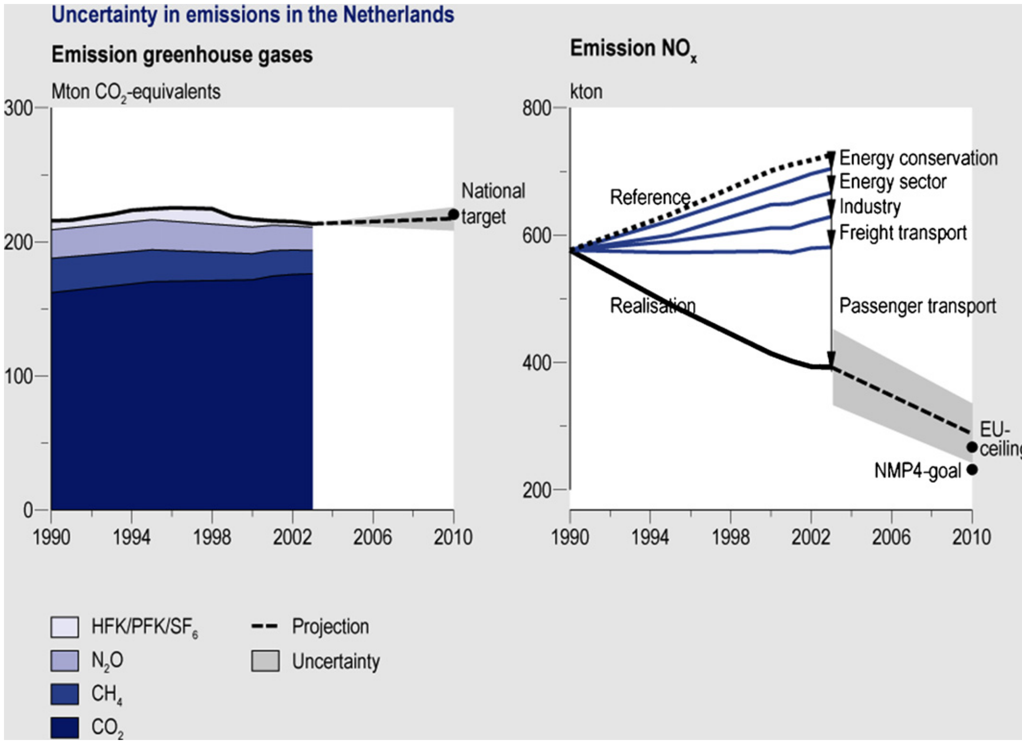


**Fig. 4 – (a) Projection-uncertainty in greenhouse gas emissions. (b) Monitoring-uncertainty and projection-uncertainty in $NO_x$ emissions (arrows indicate contribution of five policy measures that have been implemented since 1990). Modified from MNP (2005).**

graph of radiative forcing due to various greenhouse gasses, in the IPCC Third and Fourth Assessment Reports (IPCC, 2001, 2007), 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,

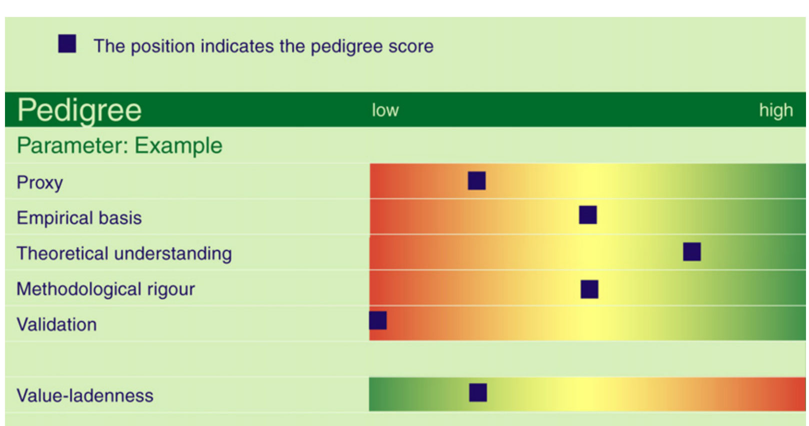


**Fig. 5 – Example pedigree chart. Gradient ranges from red (low) to green (high). For value-ladenness, this is reversed. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)**

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 Fig. 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.

### 5.4. *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, 2005), 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.

**Table 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' uncertainties 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) |

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*'' (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 2. For detailed guidance on how to apply progressive disclosure of information (PDI) in practice, see Kloprogge et al. (2007).

## 6. Discussion

### 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 (in press) 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.

### 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 (e.g., as in EEA, 2005, p. 15) could prove a useful approach, also for overcoming the problems of interpreting probability terms.

## 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 policy-making 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, 2007) and "fifty-fifty; about 50%" (MNP, 2005) 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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