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Towards Guidance in Assessing and Communicating Uncertainties

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Abstract: In the daily practice of science for policy, as experienced by governmental agencies which inform policymakers on the state and outlook of the environment, there is a pressing need for guidance in assessing and communicating uncertainties. This need extends beyond the quantitative assessment of uncertainties in model results per se, and focuses instead on the entire process of environmental assessment, running from problem framing towards reporting the results of the study. Using the Netherlands Environmental Assessment Agency (RIVM/MNP) as a case, the development, structure and content of such a guidance system is highlighted. Conditions for a successful implementation of the guidance system are discussed, and some prospects for future work are outlined.

Keywords: uncertainty assessment, communication, guidance, typology, tool catalogue, science-policy interaction

1. INTRODUCTION

At the onset of 1999, the Netherlands National Institute for Public Health and the Environment (RIVM) was faced with a credibility crisis due to public criticism in a Dutch quality newspaper by an employee of the RIVM. He critized the institute for suggesting an unjustified level of certainty in reporting their studies, by not duely accounting for uncertainty and relying too much on the virtual reality of poorly validated models. His criticism attracted much media attention in the Netherlands and triggered extensive public and political debate on the credibility, reliability and quality of environmental statistics and model-based environmental foresight, as well as on the role and position of science in policy-making (cf. pp. 285-287 in [1]; [2]).

This event does not stand alone, (see, e.g., the recent upheaval around ‘The Skeptical Environmentalist’ by Bjørn Lomborg; compare [3]), but can be seen as typical for the role and position of science for policy and society in a world which is becoming increasingly interlinked and complex. Now decisions are urgent, stakes are high and diverse, values are in dispute, uncertainty and ignorance involved are high, and trust is fragile (Funtowicz and Ravetz, [4,5,6]). All these problems are common for sustainability, risk and safety issues. The changing relationship between science, policy and society calls for processes and arrangements where issues such as transparency and novel forms of quality control (e.g. extended peer review), public participation, multiple perspectives, reflexivity, transdisciplinarity and accountability are at the forefront in establishing knowledge that is more socially robust (Gibbons and Nowotny et al. [7,8,9,10]).

At RIVM, the above-mentioned credibility crisis was the impetus for developing a system of guidance for assisting its employees in their daily practice of performing research to advise policy-makers and the public on the state and outlook of the environment, placing special focus on the assessment and communication of uncertainties. In this paper the development of this guidance system will be described, and major parts of it will be highlighted. We will end with discussing conditions for its successful implementation and outlining prospects of future work in this area.

2. ON THE DEVELOPMENT OF THE GUIDANCE SYSTEM

After the media affair in 1999 there was a national and international review of the RIVM's environmental assessment activities. These reviews led to the start-up of a multidisciplinary project on uncertainty assessment and to the development of guidance system for uncertainty assessment and communication in an environmental assessment setting. It was judged that the scope of the guidance system should extend beyond the mere quantitative assessment of uncertainties in model results per se, and should focus instead on the entire process of environmental assessment. It should involve issues such as problem framing, stakeholder participation, indicator selection, appraisal of the knowledge base, mapping and assessment of relevant uncertainties, and reporting of the uncertainty information. Choices and judgments for all these aspects are potentially of key importance for ascertaining that the most relevant uncertainties are identified and for communicating them. Therefore the guidance system should explicitly stimulate reflection on these issues, since this is expected to lead to more conscious choices and a better way of dealing with uncertainties. It should provide a prioritised list of uncertainty types and sources that need particular attention for the case at hand, in view of its societal context and the function of the assessment. Moreover the system is intended to give advance warnings of which bottlenecks can occur with respect to dealing with these uncertainties and what additional effort should then be made in the field of uncertainty assessment. It should offer advice on the selection of quantitative and qualitative methods and tools to adequately estimate uncertainties in the given context and to communicate them to scientific researchers, the clients (usually ministries), other actors in the policy process, and the broader public.

Commissioned by RIVM, the development of the guidance system started in September 2001, under the leadership of Dr. Jeroen van der Sluijs in close cooperation with RIVM and with a number of international uncertainty management specialists. In October 2001, an expert workshop was held to obtain input and feedback from the uncertainty management experts on a first sketch of the guidance system. This led to a draft version, in the form of a detailed questionnaire, which was subsequently presented to employees of the RIVM in a user workshop in November 2001. Though considered generally as a very thorough basis for uncertainty assessment, the detailed guidance document was judged by many of the users as being too comprehensive to be easily applicable in all cases. They preferred a shorter, pragmatic, easy-to-use version which could be applied at varying depths/levels, and which would offer specific hints and suggested actions on dealing with uncertainty. Therefore it was decided that in 2002 there would be developed a concise *mini-checklist* covering the major points in mapping and communicating uncertainties, as well as an associated *quickscan* version, which includes hints and preferred actions.

All this resulted in a suite of components (see figure 1), called the RIVM/MNP[1] Guidance for Uncertainty Assessment and Communication, denoted by Guidance for short in the sequel. The Guidance can be consulted in the various stages of the process by various users at a frequency and level which suits their individual needs best. For instance, *at the beginning* of a project, the guidance can play an important role in designing and elaborating the way uncertainty will be dealt with during the project; *during* a project, it can be of assistance in performing the uncertainty assessment and communicating the results; *after* a project, it can be of use in reviewing and evaluating the project. The group of intended users of the Guidance covers a large fraction of the employees of the Netherlands Environmental Assessment Agency[1] (RIVM/MNP) (e.g. project leaders, project-team members, researchers or policy advisers), as well as others (e.g. stakeholders involved in an extended peer-review of the project). Project leaders will typically use those components of the Guidance which are at a high level of aggregation (the *Mini-Checklist* and the *Quickscan*), while project-team members, researchers and policy advisers will more often also take up parts of the more detailed Guidance.

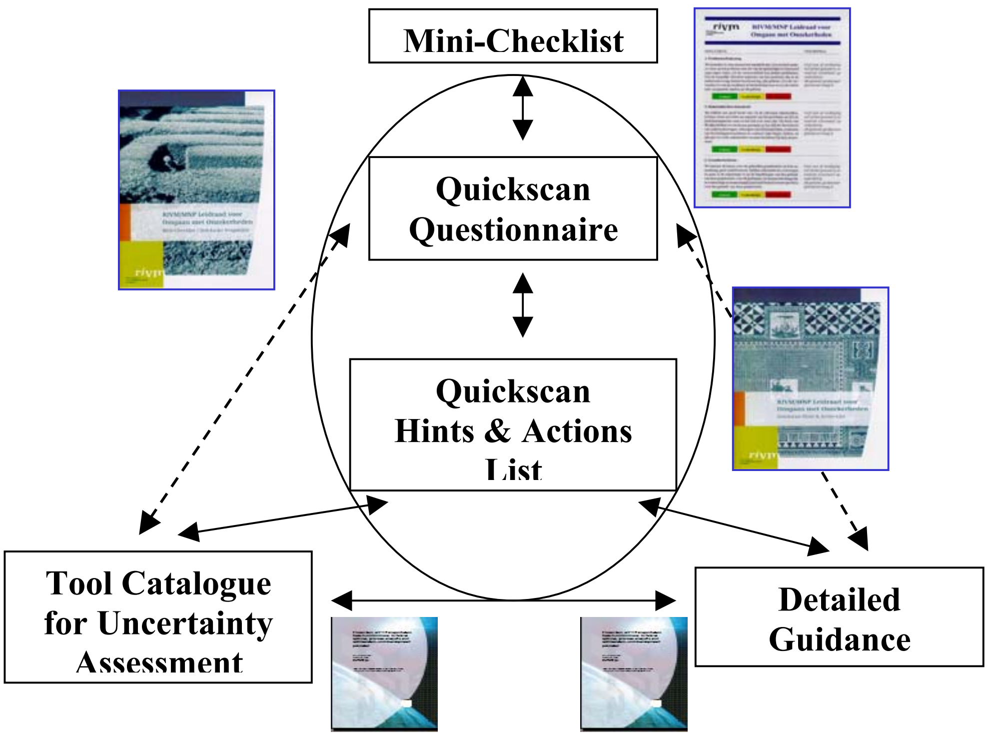

Figure 1. Structure of the RIVM/MNP Guidance for Uncertainty Assessment and Communication

The interrelationships between the components that constitute the Guidance is as follows (figure 1): The **Mini-Checklist** ([11])) is a back-of-the-envelope kind of tool which can also serve as a portal to the other components of the Guidance. By concisely presenting the potentially important issues in the various stages of the environmental assessment process - running from problem framing to reporting the results - it functions as a reminder list and instrument for reflection on the (desired) way of dealing with uncertainties and value-loadings in

[1] The Dutch name of the Netherlands Environmental Assessment Agency is 'Milieu- en Natuur Planbureau', abbreviated as MNP. It forms a part of the Netherlands National Institute for Public Health and the Environment (RIVM).

providing policy advice. It renders a brief account of the way uncertainty has been dealt with, and points to the **Quickscan Questionnaire** ([11]) if further elaboration is desired. This latter document (optionally) refers the user to the **Quickscan Hints & Actions List** ([12]) which has an advisory function and describes possible implications of the answers given to the questions in the Quickscan Questionnaire.

Some of the hints and actions point directly to parts of the **Detailed Guidance** ([13]) and the **Tool Catalogue for Uncertainty Assessment** ([14]). These documents can be considered as basic components underlying the complete Guidance. Although the Quickscan documents are presented as autonomous components which can be used in a separate mode, they are intrinsically related to these basic components. The 'Detailed Guidance' has been set up as an elaborate questionnaire for a deeper analysis of various aspects of dealing with uncertainty. It also contains a glossary of terms related to uncertainty assessment and communication. The associated 'Tool Catalogue for Uncertainty Assessment' offers information on different quantitative and qualitative methods and tools that can be utilized to assess uncertainties. The above documents documents are freely available on the Internet (see e.g. www.nusap.net).

The ultimate decision which components of the Guidance to use largely depends on the importance, the nature and the level of the uncertainties in the assessment concerned and on the resources available. The mini-checklist and the quickscan components are the parts of the Guidance that will be used most frequently. If one has the time and the mandate, then the detailed Guidance will be used to supplement and deepen the analysis. The mini-checklist and quickscan are discussed in the sequel.

3. STRUCTURE OF MINI-CHECKLIST AND QUICKSCAN DOCUMENTS

The mini-checklist concisely covers six central uncertainty-related themes in the environmental assessment process, including problem framing, stakeholder participation, selection of indicators, appraisal of the knowledge base, mapping and assessment of relevant uncertainties, reporting of the uncertainty information. It asks the user to reflect explicitly on how these issues are dealt with in the study at hand. The quickscan documents, consisting of a questionnaire and an associated hints and action list, elaborate this in more detail. In the sequel we will highlight point by point the six central themes adressed in these documents.

3.1 Problem Framing

In this stage the problem and its context and history are outlined, by identifying major issues, past work, the level of contention and the (expected) role of the assessment in the policy or decision making process. The user is explicitly asked to consider various views/perspectives on the problem, and to pay attention to the problem's interwovenness with other problems. He/she is asked to be specific on what knowledge is needed with regard to the problem, and into which research questions this is translated. Possibly relevant aspects which are not dealt with in these research questions have to be indicated. Moreover it should be outlined what role the study is expected to play in the policy process, and what the relation is with previous studies on the subject (policy context and problem history).

3.2 Involvement of Stakeholders

This step concerns the identification of the main parties (stakeholders/actors) and their views and roles with respect to the problem, as well as the aspects of the problem about which they disagree. On the basis of all this, it has to be decided *if, how* (e.g. in formulating research questions, contributing information/data, evaluating findings/results), and *when* (at the beginning, during, after) one should involve *which* stakeholders in the study.

Important in this respect is a characterization of the problem at hand in terms of a number of features: level of dissensus on policy goals regarding the problem, type of knowledge needed, and the decision stakes and uncertainties involved. This characterization can lead to useful suggestions for stakeholder involvement, and can serve as an initial step in deciding on an appropriate level and form of participation for the current study. See Box 1 below.

Box 1: Problem characteristics and suggestions for stakeholder involvement

Problem characteristics	**Suggested stakeholder involvement**
There is dissensus about policy goals with respect to the problem and/or about the direction in which solutions need to be found	Involve the stakeholders or their views in defining and framing the problem and selecting the indicators; be explicit about the limited scope of the study and its results.
Decision stakes are high	Be transparent and open: let stakeholders 'take a look behind the scenes' (in all stages of the study); aim for a broad composition of the advisory panel; involve stakeholders in the review of the study.
There is dissensus about the (type of) knowledge required to solve the problem	Discuss and – if possible –use knowledge produced or put forward by stakeholders (including other research institutes); motivate the chosen approach (especially the choices about involving certain scientific disciplines) and state the potential limitations; signal and discuss the controversies with respect to the knowledge base, and account for deviating theories and approaches to the problem; provide for external review.
Major uncertainties exist regarding the behavior of the (natural and social) system(s) under study	If feasible, use knowledge and information produced or put forward by stakeholders, including knowledge and information derived from non-scientific sources, in order to be able to come up with a study of the required quality. When communicating intermediary and final results, be specific on the lack of knowledge and clearly state the consequences for the quality and the scope of the conclusions. Provide for external review or even counter-expertise. Deliver a clear mapping of the uncertainties.

Source: [11,12]

3.3 Selection of Indicators

In environmental assessments, the relevant features of the problem under study are typically expressed in terms of indicators or target variables. Selection of indicators is therefore an important step in shaping a study, and it is important to substantiate the final choices, discussing their shortcomings and associated controversies as well. This involves judging how well the selected indicators address key aspects of the problem as it has been framed, and how much support there is among scientists and within society (including decision-makers/politicians) for the use of these indicators for the problem at hand. Moreover, there should be an examination of how to deal with a potential lack of support, giving attention to differences in views and interest, and specifying what the consequences of these differences will be for the meaning and value of the study. Consider giving the stakeholders a role in defining or revising indicators.

3.4 Appraisal of Knowledge Base

This stage is concerned with answering the question of the adequacy of the available knowledge base for the assessment. It involves questions like: What quality criteria are relevant for answering the research questions? What knowledge and methods are needed to obtain answers of the required quality? What are the most important bottlenecks in the way of achieving this, in the light of existing controversies and weaknesses in the knowledge base? What will be the effect on the quality of the results, and which actions should be taken to clear these bottlenecks? In this way the user gets useful information for (re)shaping the study, in consultation with the client, and for adequately focusing the assessment and its reporting.

3.5 Mapping and Assessment of the Relevant Uncertainties

In this step the user is asked to identify the uncertainties most relevant to the problem, and to estimate what effort will be required to map these uncertainties adequately, providing information on their extent, nature (being it epistemic or stochastic) and location. Moreover the possible consequences of the uncertainties for the conclusions of the study have to be indicated, and an indication should be given on how to assess the most important uncertainties and their consequences, within the limitations of the available resources (time, money, people, expertise, etc.). The actual planning and performing of the uncertainty assessment completes this step.

<table>
<tr><th colspan="2">Box 2: Aspects of uncertainty requiring additional attention</th></tr>
<tr><th>Problem characteristics</th><th>Uncertainty aspects requiring special attention</th></tr>
<tr><td>Various assumptions are critical</td><td>Be explicit about points of departure, assumptions and framing of the study; evaluate the critical choices made and discuss their consequences for the robustness of the policy-relevant conclusions.</td></tr>
<tr><td>The estimate of an indicator is close to a (legal) norm or (policy) target for that indicator</td><td rowspan="2">Pay additional attention to uncertainties for the indicator(s) concerned:
• indicate the nature of the uncertainties, e.g., uncertainty due to limited knowledge or due to intrinsic variability (in nature, human behavior or social systems);
• give attention to how these uncertainties can be translated in terms of accomplishing/not accomplishing policy goals, or exceeding/not exceeding norms, and to the potential size and seriousness of effects and risks;
• investigate the possibilities to reduce (policy-relevant) uncertainty, and discuss these</td></tr>
<tr><td>A small change in an indicator estimate may have a significant influence on estimated costs, impacts or risks</td></tr>
<tr><td>There is dissensus about policy goals</td><td>Pay additional attention to the role of value-laden uncertainties and stakeholder views and interests. Discuss the implications of uncertainties for the socio-political context/arena.</td></tr>
<tr><td>Decision stakes are high</td><td>Pay additional attention to the influence of views and values on the selection of indicators and on the conclusions. Discuss the implications of uncertainties for the socio-political context/arena.</td></tr>
<tr><td>There is dissensus about the (type of) knowledge required to solve the problem</td><td>Pay additional attention to the issues where the points of view differ most with respect to the (type of) knowledge required, and discuss the effects on the conclusions.</td></tr>
<tr><td>Major uncertainties exist regarding the behavior of the (natural and social) system(s) under study</td><td>Pay additional attention to the consequences of this uncertainty for the conclusions. Be explicit about ignorance and controversies, and about what these mean for the conclusions.</td></tr>
<tr><td>The assessment method used has typical uncertainties associated with it, which require additional attrention</td><td>Determine which specific uncertainties are associated with the chosen assessment method (measurements, models, scenarios, expert judgment).</td></tr>
<tr><td colspan="2">Source: [11,12]</td></tr>
</table>

To support the user in these tasks various hints and tools are provided. For example, Box 2 lists a number of triggers which point at policy-relevant uncertainties requiring additional attention. For identifying the most important uncertainties, the uncertainty matrix presented in table 1 can be used; see Box 3 for more background information. A tool catalogue is provided ([14]) to assist the user in choosing appropriate methods for dealing with the identified uncertainties. In this document comprehensive information is given on various quantitative and qualitative uncertainty assessment techniques (global sensitivity analysis, NUSAP, expert elicitation, scenario analysis, model quality assessment etc.). The presented information concerns a brief description of the specific technique and its goals, strengths and limitations, required resources, as well as guidelines for its use and warnings for typical pitfalls. It is supplemented by references to handbooks, software, example case studies, websites, experts etc. The tool catalogue is a 'living document', which will be made available on the web in the future, and to which descriptions of additional tools can be added.

Location ↓		**Level of uncertainty** *(from determinism, through probability and possibility, to ignorance)*			**Nature of uncertainty**		**Qualification of knowledge base**			**Value-ladenness of choices**		
		Statistical uncertainty	**Scenario uncertainty**	**Recognized ignorance**	**Epistemic**	**Variability**	–	**0**	+	–	**0**	+
Context												
Expert judgment												
Model	**structure**											
	implementation											
	parameters											
	inputs											
Data												
Outputs												

Table 1: Uncertainty Matrix (for explanation, see Box 3)

3.6 Reporting of Uncertainty Information

Reporting of uncertainty information preferably takes place during the whole environmental assessment process, not only at the final delivery of results. In this communication it is necessary to be aware of (i) the context of the reporting (why, to whom, on behalf of whom, when, where) and (ii) the robustness of the main messages for uncertainties in the knowledge base and for any deviations from the employed assumptions and choices. Reporting on the policy-relevant uncertainties and their possible consequences for policy making, politics and society should take place in a clear manner, tailored to the intended audience(s). In written reporting, the results should be presented in a balanced and consistent way, providing a traceable account and adequate backing of the presented material. For example, this can be achieved by offering the information in a step-wise fashion. Taking account of the fact that readers often scan a text selectively it is recommended to present important uncertainty information explicitly at strategic points, e.g. in the introduction, conclusions, summary, text-boxes. See also Box 4.

Box 3: The Uncertainty Matrix (see also Table 1)

A central element in the 'mapping and assessment' phase is the use of an extended version of the uncertainty matrix, originally proposed in Walker et al. [15]. This matrix is a heuristic device for classifying and reporting the various dimensions of uncertainty, and to improve communication among analysts as well as between them and policymakers and stakeholders. It is based on the uncertainty typology presented in [15], which classifies uncertainties according to three dimensions: their *location* (where they occur), their *level* (where uncertainty manifests itself on the gradual spectrum between deterministic knowledge and total ignorance) and their *nature* (whether uncertainty primarily stems from knowledge imperfection (epistemic uncertainty) or is a direct consequence from inherent variability/stochasticity). By explicitly adding two additional columns in the matrix denoted '*qualification of knowledge base'* and *'value-ladenness of choices*', we have extended the original uncertainty typology with two dimensions, see Table 1. The category 'qualification of knowledge' refers to the level of underpinning and backing of the information (e.g. data, theories, models, methods, argumentation etc.) involved in the assessment of the problem; it points at the methodological acceptability and the rigour and strength of the employed methods, knowledge and information, and thus it characterizes to a certain extent their (un)reliability. If desired, a so-called pedigree-analysis can be employed to assess the level of underpinning in a semi-quantitative way on basis of a number of quality criteria ([14,16]). The second additional category ('value-ladenness of choices') refers to the inevitable presence of values and biases in the various choices and assumptions involved. This concerns choices and assumptions regarding the way the scientific questions are framed, data are selected, interpreted and rejected, methodologies and models are devised and used, explanations and conclusions are formulated etc.

Both added dimensions characterize important features which directly relate to uncertainty: If underpinning is weak, this indicates that the statement of concern is surrounded by much (knowledge-related) uncertainty. If value-ladenness is high for relevant parts of the assessment, then it is imperative to analyze whether or not the results of the study are highly influenced by the choices and assumptions involved, and whether this could lead to a certain arbitrariness, ambiguity or uncertainty of the policy-relevant conclusions. This could then be a reason to explicitly deal with different views and perspectives in the assessment and to discuss the scope and robustness of the conclusions in an explicit manner.

Source: [12]

4. DISCUSSION

The foregoing illustrates that the guidance system provides structure to the task of uncertainty management and can be employed in a flexible way. The Guidance stimulates reflection and deliberation on how uncertainties are (to be) handled and communicated effectively and helps to avoid pitfalls. Tools for uncertainty assessment are made more easily available, and can be selected in a more tailored manner, on basis of problem characteristics. Although the guidance system was initially developed in the context of environmental assessments, it can be applied in other application areas as well, with some minor adaptations as appropriate.

For its success, some conditions are essential. Firstly, the commitment of the higher management is crucial, since time and effort spent on dealing with uncertainties must be considered as relevant. By its primary focus on the policy-relevance of uncertainties, the Guidance puts this issue explicitly to the fore. Secondly, it would certainly help if the use of the Guidance was included as standard activity in the prevailing project management. At RIVM/MNP this has been established by including the Guidance formally in the quality assurance system. Thirdly, its further application and institutionalization will require motivating and training the potential users of the Guidance, showing them the benefits of its use. We are currently developing training sessions for employees of the RIVM/MNP in the use of the Guidance. To support the introduction in daily practice, a web-based version of the Guidance is under construction, providing quick and easy access to its various parts. We hope to stimulate this introduction process further by providing appropriate uncertainty assessment tools, and by gradually building an expertise network and a 'good-practice examples' data-base in using the Guidance.

In fact, we currently are only at the start of implementing the presented systematic ideas of uncertainty management in an institutional setting. The above-mentioned activities must therefore be considered as first steps. In due time - after its fuller implementation - the use of the Guidance will be evaluated, leading possibly to further adaptations. For the time being we can already identify two major issues which will deserve future attention: The first one refers to the further deployment and development of the tool catalogue with methods for: (i) propagating and analysing qualitative and semi-quantitative uncertainty information (e.g. concerning value-loadings, assumptions, pedigree scores), especially in expert-reasoning and model-based calculation 'chains'; and for (ii) synthesising qualitative and (semi)-quantitative uncertainty information ([16]). The second issue concerns the analysis of various contexts of science, policy and society interactions in order to find suitable arrangements and forms for knowledge production and uncertainty communication; thus enhancing the effective use of science for policy or society.

Notwithstanding that there is still a long way to go, one can consider the Guidance - with its specific focus on problem context and socio-political embedding, accountability, transparency and reflexivity, participation and extended peer review - as a useful contribution towards new social practice of science in a postmodern era, as exemplified by e.g. the post-normal science and mode 2 science paradigms ([4-10]).

Box 4: Reporting of Uncertainty Information

Communicating and reporting about uncertainty entails a number of issues that should be taken into consideration. The RIVM/MNP Guidance discerns (1) context of communication of uncertainty; (2) target audiences; (3) language; (4) methods; (5) format and (6) content.

With regard to *context* authors have to ask themselves why the uncertainty is being reported (e.g. political purpose, scientific purposes, required by legislation, requested by stakeholders), and at which stage, and what setting (e.g. report, meeting, press article, internet, scientific journal). This will influence the scope of the reporting.

The *target audiences* may stretch out over the stakeholders for the problem of concern. Although the target audience might not correspond to the whole set of stakeholders, it is surely a subset of those. The type of audience will determine amongst other things the 'language' of the communication/report as well as the main messages of interest. Since the audience can be quite disverse or disparate, clear and transparant communication of the results is required, but misinterpretations can not always be avoided.

The *language* used in the communication and reporting of uncertainty is one of the most important issues. Careful design of communication and reporting should be done in order to avoid information divide, misunderstandings, and misinterpretations. The communication of uncertainty should be understandable by the audience. There should be clear guidelines to facilitate clear and consistent use of terms provided. Values should be made explicit in the reporting process. Potential ambiguity in the wording of the report or in use of metaphors should better be avoided.

The *method* used to manage uncertainty (quantitative sensitivity and uncertainty analysis, quality assurance (e.g. NUSAP, pedigree analysis) etc.) and hence, the type of information generated, is a crucial aspect of communicating and reporting uncertainty and should be described. Uncertainty methods can operate in the foreground when applied explicitly to produce information on uncertainty (e.g. written material, graphs), or in the background as when run 'behind' a model and results are embedded in the output (e.g. model outputs, scenarios).

A variety of different reporting *formats* and media can be used (numbers, words, narratives, graphs, pictures, multimedia, internet). No one format is more valid than others. The choice of format depends on communication settings, type of audience, and uncertainty management methods.

With regard to *content* one could think of making explicit the major assumptions on which the main messages are based, discussing the robustness of the major conclusions in the light of these assumptions as well as of uncertainties in the underlying knowledge base. Moreover important areas of ignorance and controversies should be stated explicitly, giving background on how these issues have been dealt with, and what this means for the main conclusions. If considered relevant for the given context, clear information could be given on the nature and causes of policy-relevant uncertainties and on the potential consequences for policy, politics and society (e.g. in terms of effects and risks). Indicate – if considered policy relevant – what can and can not be done about these uncertainties, and which uncertainty aspects deserve additional attention in the future.

Source: [11,12,13]

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