14 Reflective approaches to uncertainty assessment and communication

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1 Introduction

Policy decisions in many areas involving science, including the environment and public health, are both complex and contested. Typically there are no *facts* that entail a unique correct policy. Furthermore, political decisions on these problems will need to be made before conclusive scientific evidence is available. Decision stakes are high: The impacts of *wrong* decisions based on the available limited knowledge can be huge. Actors disagree on the values that should guide the decision-making. The available knowledge bases are typically characterised by imperfect understanding (and imperfect reduction into models) of the complex systems involved. Models, scenarios and assumptions dominate assessment of these problems, and many (hidden) value loadings reside in problem frames, indicators chosen and assumptions made.

The evidence that is embodied in scientific policy advice under such *post-normal* (Funtowicz and Ravetz 1993) conditions requires quality assessment. Advice should be relevant to the policy issue, scientifically tenable and robust under societal scrutiny. Governmental and intergovernmental agencies that inform policy and the public about complex risks increasingly recognise that uncertainty and disagreement can no longer be suppressed or denied, but need to be dealt with in a transparent and effective manner. In response to emerging needs, several institutions that interface science and policy have adopted *knowledge* quality assessment approaches, where *knowledge* refers to any information that is accepted into a debate (UK Strategy Unit 2002; EPA 2003; MNP/UU 2003; IPCC 2005). One of these is the PBL Netherlands Environmental Assessment Agency (Planbureau voor de Leefomgeving or PBL in Dutch; part of which – then named MNP – was previously associated

* The views expressed are those of the authors and do not represent necessarily those of the European Commission.

with the National Institute for Public Health and the Environment, RIVM), a governmental agency that performs independent scientific assessments and policy evaluations. PBL has recently implemented a comprehensive, multi-disciplinary checklist approach to knowledge quality assessment, which takes into account the societal context of knowledge production, which will be discussed later on in this chapter.

Such a structured approach to knowledge quality assessment can help to achieve a better awareness of the limits of science in relation to the task of knowledge producers to provide a scientific basis for policy debate. One of the responsibilities of scientific advisers is to point out those situations in which the focus cannot primarily lie on *reducing uncertainties* but where decision-makers will have to *cope with untameable uncertainties and complexities*. This can avoid misunderstandings and undue expectations of the role and competence of science in complex environmental problems.

2 Models cannot remedy ignorance

Since the 1980s, computer models are increasingly being used in complex environmental assessments and foresight: they enable analysts to simulate reality and run several scenarios, thereby integrating knowledge from different disciplines. Applied systems analysis has become the dominant method in environmental assessment. The assumption ladenness of the models themselves, the use of models, the degree to which they can be validated or evaluated, and the transparency of models have been criticised over the years.

To give some examples, Hornberger and Spear (1981, cited in Saltelli 2002) argued that non-linear models with many parameters generally have many degrees of freedom and can be made to produce virtually any desired behaviour, often with both plausible structure and parameter values.

Oreskes *et al.* (1994) highlighted the assumption ladenness of models and argued that natural systems are never closed. They argued that earth system models can, in principle, never be *verified* or *validated*, but only *confirmed* or *corroborated*. Beven's (2002) concept of equifinality (the phenomenon that models may be non-unique in their accuracy of both reproduction observations and prediction) and Beck's (2002) closely related notion that almost all models suffer from a lack of identifiability (many combinations of values for the model's parameters may permit the model to fit the observed data more or less equally well) further emphasise the problematic nature of models and model predictions as a source of knowledge for decision-making.

Yearley (1996) argued that values and value-laden assumptions enter into the formulation of environmental issues before the *facts* are even established by science. Yearley gives examples regarding carbon dioxide, ozone destroying chemicals and biodiversity and concludes that though, at first sight, science might be thought to be clearly universal and thus incontestably applicable to global problems, in practice its universality can be deconstructed and undermined. A similar argument is made by Stirling (1999, 2001), who stresses the critical dependence of final results of risk assessment studies to the starting assumptions made.

Van der Sluijs (1997; Van der Sluijs *et al.* 1998) argued that the building of environmental assessment models inevitably involves subjective choices and value-laden assumptions. Lack of transparency with regard to these assumptions and uncertainties, and lack of reflection on how knowledge that is conditioned on these models and its assumptions differs from well-established knowledge, lead to misunderstandings in the science policy interface on the nature of this type of knowledge. There is a tendency to treat this knowledge as if it is not different from well-established knowledge. The history has many examples of scandals and loss of trust in the scientific basis for policies based on lack of understanding of the nature of knowledge stemming from model-based assessment and foresight. A classic example is the scandal of the IIASA energy scenarios in the 1980s: In a critical review of the models used for these scenarios, Keepin and Wynne (1984) concluded that: 'Despite the appearance of analytical rigour, IIASA's widely acclaimed global energy projections are highly unstable and based on informal guesswork. This results from inadequate peer review and quality control, raising questions about political bias in scientific analysis.' They made a strong case for the need to conduct a rigorous analysis of assumptions in forecasting tools used in the energy field, and the need to test the robustness and sensitivity of results. They argue strongly for an open and accessible documentation and rigorous peer review. The case led to a crisis within the institute and has triggered institutional learning towards more attention for uncertainty and quality control to regain credibility for their work with peer communities and the public.

More recently the Netherlands National Institute for Public Health and the Environment (RIVM) encountered a similar scandal: Early in 1999, H. de Kwaadsteniet, a senior statistician, accused the institute of 'lies and deceit' in their State of the Environment Reports and Environmental Outlooks. In a Dutch quality newspaper (*Trouw*) he criticised RIVM for basing their studies on the *virtual reality* of poorly validated computer models while RIVM presents these results as point values with unwarranted significant digits and without elaborating the uncertainties.

It triggered a vehement public debate on the credibility and reliability of environmental numbers and models. The case got front page and prime time coverage in the mass media over a period of several months and led to debate in the Netherlands' Parliament (Van der Sluijs 2002; Petersen 2006b). The case also triggered a learning process within the RIVM and led to the development of a guidance for uncertainty assessment and communication for the institute (see Section 3.2).

3 Reflective approaches to uncertainty

Until recently, the field of uncertainty analysis mainly evolved around mathematical methods such as sensitivity analysis and Monte Carlo techniques. These tools address quantitative dimensions of uncertainty using sophisticated algorithms (Saltelli *et al.* 2000, 2004). Although these quantitative techniques are essential in any uncertainty analysis, they can only account for what can be quantified and thus provide only a partial insight in what usually is a very complex mass of uncertainties involving technical, methodological, epistemological and societal dimensions. For the class of complex problems that we are concerned with in this chapter, it is often the case that unquantifiable uncertainties may well dominate the quantifiable ones, which implies that these techniques are of limited value for this particular class of problems.

In the school of post-normal science, several new multi-dimensional and reflective approaches to knowledge quality assessment have been developed to systematically address unquantifiable dimensions of uncertainty. We will discuss two key examples here, the NUSAP system and the aforementioned MNP Guidance for Uncertainty Assessment and Communication.

3.1 The NUSAP system

NUSAP is a notational system proposed by Funtowicz and Ravetz (1990), which aims to provide an analysis and diagnosis of uncertainty in the knowledge base of complex (environmental) policy problems. It captures both quantitative and qualitative dimensions of uncertainty and enables one to communicate these in a standardised and self-explanatory way. The basic idea is to qualify quantities using the five qualifiers of the NUSAP acronym: Numeral, Unit, Spread, Assessment and Pedigree.

The first qualifier is Numeral; this will usually be an ordinary number; but when appropriate it can be a more general quantity, such as the expression 'a million' (which is not the same as the number lying between 999,999 and 1,000,001). Second comes Unit, which may be of the conventional sort, but which may also contain extra information, as the date at which the unit is evaluated (most commonly with money). The middle category is Spread, which generalises from the *random error* of experiments or the *variance* of statistics. Although Spread is usually conveyed by a number (either ±, % or *factor of*), it is not an ordinary quantity, for its own inexactness is not of the same sort as that of measurements. Methods to address Spread can be statistical data analysis, sensitivity analysis or Monte Carlo analysis possibly in combination with expert elicitation.

The remaining two categories constitute the more qualitative side of the NUSAP expression. Assessment expresses evaluative judgements about the information. In the case of statistical tests, this might be the significance level; in the case of numerical estimates for policy purposes, it might be the qualifier *optimistic* or *pessimistic*. In some experimental fields, information is given with two ± terms, of which the first is the spread, or random error, and the second is the *systematic error* which must be estimated on the basis of the history of the measurement, and which corresponds to our assessment. It might be thought that the *systematic error* must always be less than the *experimental error*, or else the stated ‹ would be meaningless or misleading. But the *systematic error* can be well estimated only in retrospect, and then it can give surprises.

Finally, there is Pedigree, which conveys an evaluative account of the production process of information, and indicates different aspects of the underpinning of the numbers and scientific status of the knowledge used. Pedigree is expressed by means of a set of pedigree criteria to assess these different aspects. Assessment of pedigree involves qualitative expert judgement. To minimise arbitrariness and subjectivity in measuring strength, a pedigree matrix is used to code qualitative expert judgments for each criterion into a discrete numeral scale from 0 (weak) to, for example, 4 (strong) with linguistic descriptions (modes) of each level on the scale. Each special sort of information has its own aspects that are key to its pedigree, so different pedigree matrices using different pedigree criteria can be used to qualify different sorts of information. Pedigree assessment can be further extended to also address societal dimensions of uncertainty, using criteria addressing different types of value loading, quality of problem frames, etc. (Corral 2000; Craye, Van der Sluijs and Funtowicz, 2005; Kloprogge, Van der Sluijs and Petersen 2005).

NUSAP provides insight on two independent properties related to uncertainty in numbers, namely spread and strength. Spread expresses inexactness whereas strength expresses the methodological and epistemological limitations of the underlying knowledge base. The two metrics can be combined in a Diagnostic Diagram. This maps strength of, for instance, model parameters and sensitivity of model outcome to spread in these model parameters. Neither spread alone nor strength alone is a sufficient measure for quality. Robustness of model output to parameter strength could be good even if parameter strength is low, if the spread in that parameter has a negligible effect on model outputs. In this situation, our ignorance of the true value of the parameter has no immediate consequences. Alternatively, model outputs can be robust against parameter spread even if its relative contribution to the total spread in the model is high provided that parameter strength is also high. In the latter case, the uncertainty in the model outcome adequately reflects the inherent irreducible uncertainty in the system represented by the model. Uncertainty then is a property of the modelled system and does not stem from imperfect knowledge on that system. Mapping components of the knowledge base in a diagnostic diagram thus reveals the weakest spots and helps in the setting of priorities for improvement.

Experiences so far, as reviewed in Van der Sluijs *et al.* (2005), have shown that the NUSAP method is applicable not only to relatively simple calculation schemes but also to complex models in a meaningful way. It is also useful to assess not only parameter uncertainty but also (model) assumptions. Especially when extended to include societal dimensions of uncertainty such as problem framing and value loadings, it promotes reflexivity and collective learning. The task of quality control in the knowledge base of complex and controversial (environmental) policy problems is a complicated one and the NUSAP method disciplines and supports this process by facilitating and structuring a creative reflexive process and in-depth review of the limitations of a given knowledge base. NUSAP makes the various dimensions of uncertainty explicit and enables a systematic and effective societal reflection on them. It provides a diagnostic tool for assessing the robustness of a given knowledge base for policymaking and promotes criticism by clients and users of all sorts, expert and lay and will thereby support extended peer review processes.

3.2 The RIVM/MNP Uncertainty Guidance

After the aforementioned De Kwaadsteniet affair in 1999, a national and international review of the Netherlands Environmental Assessment Agency (then named RIVM/MNP) was undertaken. The auditors recommended that MNP should start a project to systematically address terminology, methodology, interpretation and communication of uncertainty. Following these recommendations, MNP commissioned Utrecht University to develop a practical guidance for uncertainty assessment and communication in environmental assessment studies. This was done in

Table 14.1 *Foci and key issues in knowledge quality assessment*

Foci	Key issues
Problem framing	Other problem views; interwovenness with other problems; system boundaries; role of results in policy process; relation to previous assessments
Involvement of stakeholders	Identifying stakeholders; their views and roles; controversies; mode of involvement
Selection of indicators	Adequate backing for selection; alternative indicators; support for selection in science, society and politics
Appraisal of knowledge base	Quality required; bottlenecks in available knowledge and methods; impact of bottlenecks on quality of results
Mapping and assessing relevant uncertainties	Identification and prioritisation of key uncertainties; choice of methods to assess these; assessing robustness of conclusions
Reporting uncertainty information	Context of reporting; robustness and clarity of main messages; policy implications of uncertainty; balanced and consistent representation in progressive disclosure of uncertainty information; traceability and adequate backing

consultation with an international team of uncertainty experts. 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.

The RIVM/MNP Guidance for Uncertainty Assessment and Communication (Janssen *et al.* 2003, 2005; Petersen *et al.* 2003; Van der Sluijs *et al.* 2003, 2004; Petersen 2006a) aims to facilitate the process of dealing with uncertainties throughout the whole scientific assessment process (see Table 14.1). It explicitly addresses institutional aspects of knowledge development, openly deals with indeterminacy, ignorance, assumptions and value loadings. It thereby facilitates a profound societal debate and a negotiated management of risks. The Guidance is not set up as a protocol. Instead, it provides a heuristic that encourages self-evaluative systematisation and reflexivity on pitfalls in knowledge production and use. It also provides diagnostic help as to where uncertainty may occur and why. This can contribute to more conscious, explicit, argued and well-documented choices.

Following a checklist approach inspired by Risbey *et al.* (2005), the Guidance consists of a layered set of instruments (Mini-Checklist, Quickscan and Detailed Guidance) with increasing level of detail and sophistication. It can be used by practitioners as a (self-elicitation) instrument or by project managers as a guiding instrument in problem framing and project design. Using the Mini-Checklist and Quickscan Questionnaire, the analyst can flag key issues that need further consideration. Depending on what is flagged as salient, the analyst is referred to specific sections in a separate Hints & Actions document and in the Detailed Guidance. Since the number of cross-references between the documents comprising the Guidance is quite large, a publicly available interactive web application has been implemented (http://leidraad.pbl.nl). This web application also offers a prioritised to-do list of uncertainty assessment actions, and generates reports of sessions (traceability and documentation), which enables internal and external review.

In order to facilitate communication about the different types of uncertainty that arise in scientific assessments, an uncertainty typology is part of the Guidance. The typology is based on a conceptual framework that resulted from a process involving an international group of uncertainty experts most of whom participated in developing or reviewing the Guidance (Walker *et al.* 2003). Uncertainty can be classified along the following dimensions: its *location* (where it occurs), its *level* (whether it can best be characterised as statistical uncertainty, scenario uncertainty or recognised ignorance) and its *nature* (whether uncertainty primarily stems from knowledge imperfection or is a direct consequence of inherent variability). In addition, the typology distinguishes the dimensions *qualification of knowledge base* (what are weak and strong parts in the assessment) and *value-ladenness of choices* (what biases may shape the assessment). The typology is presented as a matrix. This uncertainty matrix is used as an instrument for generating an overview of where one expects the most important (policy-relevant) uncertainties to be located (the first dimension), and how these can be further characterised in terms of the other uncertainty dimensions mentioned. The matrix can be used as a scanning tool to identify areas where a more elaborate uncertainty assessment is required. The different cells in the matrix are linked to available uncertainty assessment tools suitable for tackling that particular uncertainty type. These tools are described in a Tool Catalogue that aims to assist the analyst in choosing appropriate methods.

The Tool Catalogue provides practical (*how to*) information on state-of-the-art quantitative and qualitative uncertainty assessment techniques, including sensitivity analysis, NUSAP (Funtowicz and Ravetz 1990; Van der Sluijs *et al.* 2005), expert elicitation, scenario analysis, and model quality assistance (Risbey *et al.* 2005). A brief description of each tool is given along with 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, web resources and experts. The tool catalogue is a *living document* available on the web, to which new tools can be added.

4 Conclusion

Complex environmental problems have characteristics that require a post-normal science approach in which uncertainty, assumptions and value loadings are subject to explicit and systematic analysis and communication. For this class of problems, knowledge quality assessment should be at the heart of the science-society interface, in order to promote a better awareness of the limits of science in relation to the task of knowledge producers to provide a scientific basis for policy debate. In combination with a widening in focus from *reducing uncertainties* to *coping with untameable uncertainties and complexities*, this can help to avoid misunderstandings and undue expectations of the role and competence of science in complex environmental problems.

Tools and approaches for knowledge quality assessment such as NUSAP and the checklist based Guidance for Uncertainty Assessment and Communication of PBL Netherlands Environmental Assessment Agency, have now been developed, tested and made available. NUSAP helps to systematically assess the technical, methodological and epistemic uncertainties in knowledge claims and helps to focus research efforts on the potentially most problematic parameters and assumptions in models, identifying at the same time specific weaknesses and biases in the knowledge base.

PBL's Uncertainty Guidance structures the tasks of uncertainty management, promotes reflection and forces deliberate choice on how uncertainties are handled. It helps to avoid pitfalls in the assessment and communication of uncertainty.

Similar to a patient information leaflet alerting the patient to risks and unsuitable uses of a medicine, knowledge quality assessment enables the delivery of policy-relevant quantitative information together with the essential warnings on its limitations and pitfalls. It thereby promotes the responsible and effective use of the information in policy processes.

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