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THE PRECAUTIONARY PRINCIPLE: IMPLICATIONS FOR RISK MANAGEMENT STRATEGIES

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Abstract. The European Commission has published a Communication on the Precautionary Principle and a White Book on Governance. These provide us (as research civil servants of the Commission) an institutional framework for handling scientific information that is often incomplete, uncertain, and contested. But, although the Precautionary Principle is intuitively straightforward to understand, there is no agreed way of applying it to real decision-making. To meet this perceived need, researchers have proposed a vast number of taxonomies. These include ignorance auditing, type one-two-three errors, a combination of uncertainty and decision stakes through post-normal science and the plotting of ignorance of probabilities against ignorance of consequences. Any of these could be used to define a precautionary principle region inside a multidimensional space and to position an issue within that region. The role of anticipatory research is clearly critical but scientific input is only part of the picture. It is difficult to imagine an issue where the application of the Precautionary Principle would be non-contentious. From genetically-modified food to electro-smog, from climate change to hormone growth in meat, it is clear that: 1) risk and cost-benefit are only part of the picture; 2) there are ethical issues involved; 3) there is a plurality of interests and perspectives that are often in conflict; 4) there will be losers and winners whatever decision is made. Operationalization of the Precautionary Principle must preserve transparency. Only in this way will the incommensurable costs and benefits associated with different stakeholders be registered. A typical decision will include the following sorts of considerations: 1) the commercial interests of companies and the communities that depend on them; 2) the worldviews of those who might want a greener, less consumerist society and/or who believe in the sanctity of human or animal life; 3) potential benefits such as enabling the world's poor to improve farming; 4) risks such as pollution, gene-flow, or the effects of climate change. In this paper we will discuss the use of a combination of methods on which we have worked and that we consider useful to frame the debate and facilitate the dialogue among stakeholders on where and how to apply the Precautionary Principle.

Key words:
Quality, Uncertainty, Post-Normal Science, Sensitivity analysis, Global sensitivity analysis, NUSAP System

HEURISTIC TAXONOMIES

In their classic paper, Dovers and Handmer [1] came to the conclusion that the Precautionary Principle (PP) is no more operational than the injunction – sustainability, which it is meant to inform. Since then, there has been a vast production of heuristic taxonomies that could play a role in the operationalization of the PP: the ignorance auditing is one example; type one-two-three errors is another. Post-Normal Science with its emphasis on ignorance-stakes diagrams (Fig. 1), still another. Other authors plot ignorance of probabilities versus ignorance of consequences, thereby identifying the "black ignorance"

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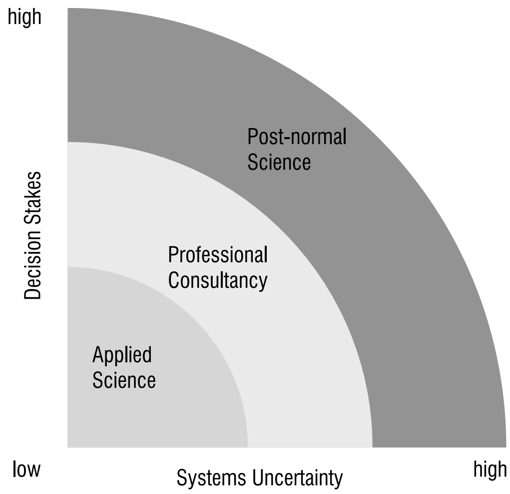

Fig. 1. Ignorance-stakes plot [2].

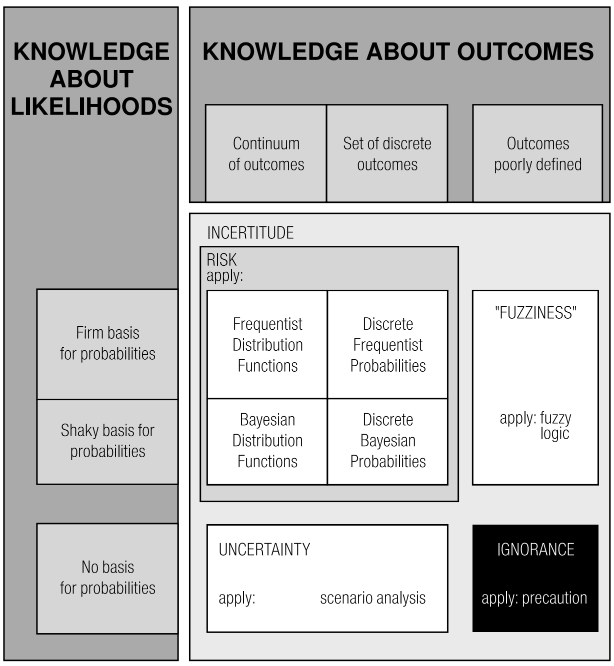

Fig. 2. The concepts of "Incertitude", "Risk", "Uncertainty" and "Ignorance" [3].

region where the PP would be more cogently called into place (Figs. 2, 3).

Taken literally, these taxonomies strive to "position" an issue (e.g., global change, genetically-modified organisms (GMO), whether to build or not a potentially polluting plant) on some kind of graph, such as the ignorance-stakes plots just mentioned, so that one can automatically say: "Ah! You see, this really falls within the PP region!".

For this literal taxonomic approach to be of normative use, one would need that the taxonomy used (e.g., again ignorance-stakes, to make an example) has been accepted as a procedure (a rather fragile, unrealistic assumption), and that the distinctions made in the axes have been agreed upon. It is fair to say that only qualitative or semi-quantitative metrics have been proposed to gauge, for example, ignorance and stakes. This approach is consistent with the heuristic character of the representations.

Let us imagine that one step further has been made, and that a panel of experts has agreed to use the NUSAP system (Fig. 4), a well known procedure for describing the quality of information by a set of attributes, and some form of more or less formalized uncertainty and sensitivity analysis (Table 1). We shall go back to these techniques later in this presentation. The panel could at this point go back to its "ignorance-stakes " diagram and perhaps represent an issue as a cloud, rather than as a point, in a normative taxonomic chart.

The problem is that any such mapping in itself is also fraught with its own type of uncertainties.

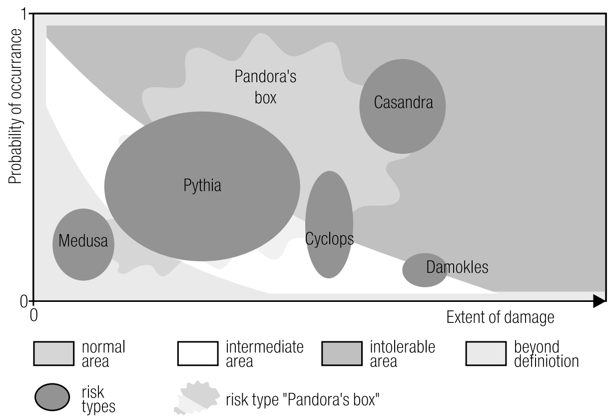

Fig. 3. A taxonomy of risk after [4].

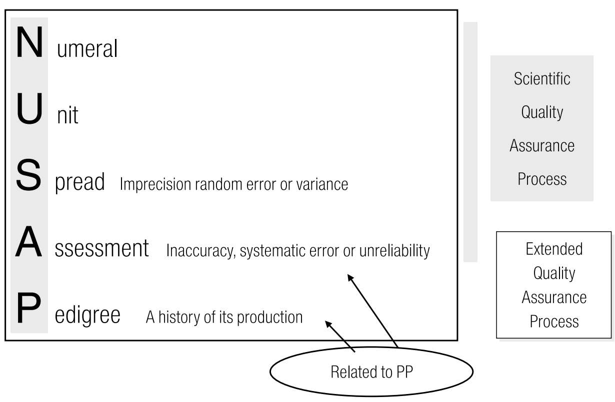

Fig. 4. The NUSAP system. Available from: http://www.nusap.net/.

Table 1. Variance-based, global sensitivity analysis techniques

Variance-based techniques imply that model output is a scalar function whose empirical distribution function can be generated by sampling from a set on input factors that constitute the input for, y, i.e., $y = f(x_1, x_2,...., x_k)$. Here k is the dimensionality of the input space and f is an analytic formula or a computer code that for an assigned set of $x_1, x_2,..., x_k$ univocally determine y. This problem setting is the one most usually found in assessment studies, but the procedure applies equally when an error term for y is included. Our sensitivity analysis works by computing fractional variances such as

$$V_j = V_i[E_{\sim i}(y|x_i)]$$

where the inner mean is taken over all factors but x_1, being x_1 fixed to one of its possible values, say x_1^*, and the outer variance is taken over all possible values of x_1^*. V_j is called the first order effect of x_1 on Y. As discussed in [5], V_j is also the statistical measure to use in order to make an educated guess for the problem: “Why factor should I fix in order to reduce the most variance of the output?”. The factor with the highest V_j is the obvious response, regardless of the independence of the input and of the additivity of the model. We also use another, apparently more arcane measure, i.e.,

$$v_1 = E_{\sim i}[V_1(Y|x_{\sim i})]$$

where this time the inner variance is taken over x_1, being all other factors are fixed at a point, say $x_{\sim i} = x^*_{\sim i}$ in the (k – 1) dimensional space, and the outer mean over all possible values of $x^*_{\sim 1}$. v_1 is the statistical measure to use in order to solve the question: “What is the factor that — being left last in the determination sequence, would leave the largest residual variance?”. As discussed in [5], the factor with the highest v_1 is the logical choice. Another way of looking at the V and v_1 measures is that V describes the effect of x_1 by itself on Y, while v_1 measures the total effect of x_1 on Y, inclusive of all interactions involving x_1 and the members of the complementary set $x_{\sim i}$. v_1 is relevant to the problem setting of fixing, for simulation purposes, non-influential factors, as a zero value for v_1 implies total non-influence. Estimation procedures for V and v_1 are discussed in [6,7].

Even within the context of the two assumptions just mentioned (axes and metrics agreed upon), one runs into problems of the “pedigree” of the information (the quality of the process that produced it) and what the relative uncertainties are (see Fig. 5 for an example of pedigree assessment. Available from: http://www.nusap.net).

The cogency of the case for invoking the PP would at this point be made on the basis of the overlap between the cloud representing the issue and the frightening black portion of the diagram. This literal taxonomic approach to the discussion on how to make sense of PP is clearly an attempt to find a technological fix to the problem (use

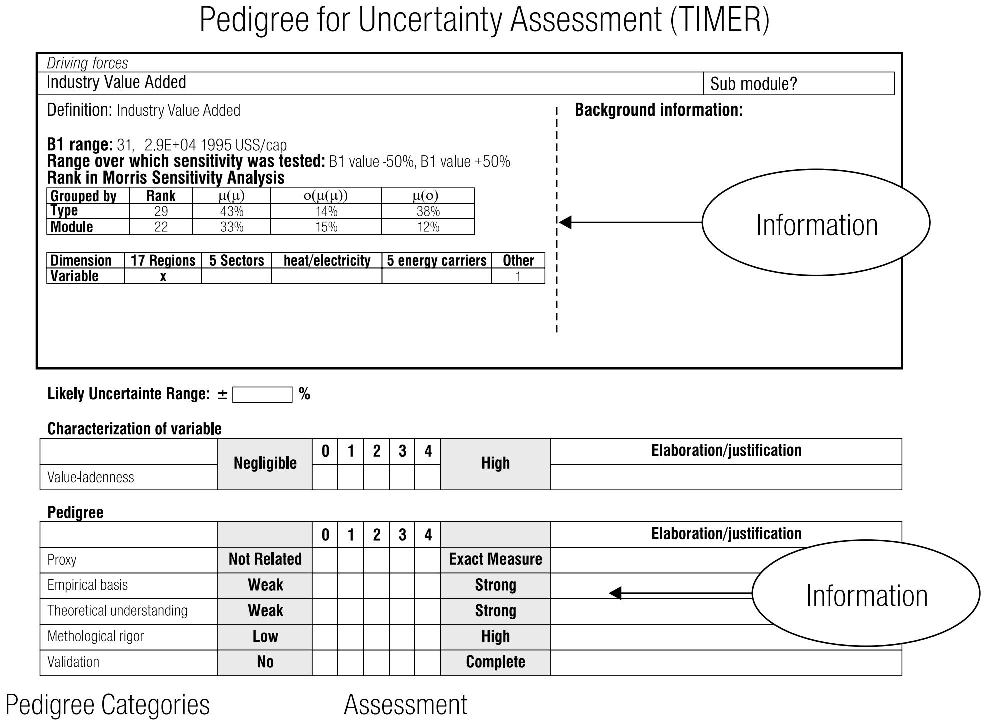

Fig. 5. Example of pedigree assessment [8].

the procedure through the prescribed step and the issue is classified).

It must be clear that these solutions – albeit alluring for the technical people – are unlikely to make PP more digestible in practice. Nevertheless, we shall devote one part of this presentation to see what use can be made of them. Our viewpoint is that of researchers from within the European Commission, confronted with a demand for scientific inputs to policy in the context of precaution.

According to the European Commission [9], the Precautionary Principle has three legal implications:

- "... it enables and sometimes obliges the regulatory authorities to take action when there is scientific uncertainty and risk but a direct causal link cannot be established.[...]
- the Precautionary Principle sometimes entails placing the burden of proof on the applicant manufacturer [...]
- the Precautionary Principle also enables the affected persons to control, if necessary by means of action before the courts, the exercise of regulatory discretion in risk management."

The wording of this statement, with the recurrence to "sometimes" and "if necessary" suggests that the process of appeal for scope of PP application is in fact a negotiation for which procedural rules still need to be established.

One would expect in general that "quality-of-information" strategies can help providing circumstantial evidence about the existence of a case for invoking PP (or not invoking it!). Thus if information is of low strength in relation to its criticality as evidence, then there might be a case for precaution (at least!) in its interpretation and use.

A crucial aspect surrounding any PP discussion is polarization. Whatever the case at hand, one should acknowledge that "all parties deal with environmental information in a selective way, or even manipulate it" [10]. One could easily substitute environmental with health, economy, use of resources etc., or simply say that whenever a plurality of perspectives or interests is at stake, all parties may manipulate the information for their advantage. This would sound obvious and not worth if one were not confronted systematically with "scientific evidence", or "mathematical/rational proof", put forward by experts in connection with these issues, which involve irreducible complexity. Another example of what could be termed scientific hubris is the recurrence to radical subjectivism. Starting from De Finetti's probabilistic subjectivity viewpoint, some draw the conclusion that all statements about the world are merely subjective, hence all issues can be tackled by Bayesian analysis and decision theory. The existence of ignorance as distinguished from uncertainty is discounted.

A first demand that methodologists should meet is then that of transparency, i.e., the degree of uncertainty should be revealed, and the multiplicity of views and theories brought into the open.

Another aspect worth pondering is the instrumental use of the PP; its use can be advocated by all parties with a stake in the issue. This is an extension of what can be called the "politisation" of uncertainty. For example:

- there will be people ready to sustain Zambia, Mozambique and Tanzania's decision (August 2002) not to accept US GM grain as a sound application of the PP, although the reasons for rejection were more linked to their exports to Europe, than to actual fear that this food might actually be harmful to citizens.
- D. Rumsfeld invoking and anticipatory war to Iraq with a formulation very close to PP arguments*.
- Lomborg [11], who has been the center of many recent controversies, in analyzing the implications of the Kyoto Protocols in conjunction with various scenarios prepared by Intergovernmental Panel on Climate Change (IPCC), complains that the strategies suggested as preferred by the IPCC experts are not those that would minimize losses, or increase universal welfare but those that would lead the

* "... it is difficult to get an agreement on an interpretation of facts even when they already happened, let alone before they happen"; "It is not possible to find hard evidence that something is going to happen two, four, eight or a year down the road – you will have known it happened after it happens . . . now can anyone will be always able to say, even after the fact, that there isn't sufficient evidence, that you don't have proof beyond a reasonable doubt. You'll know an event occurred, but even after it occurs, it's very difficult to get perfect evidence."; "It is the task of taking these disparate pieces and putting them together so that the people can make their own judgement, not for us to prove anything. What they have to do is they have to say what does a reasonable person conclude are the risks from this? Are the risks greater of the UN for example trying to enforce their resolution or are the risks greater of not doing that? Always there are risks on both sides." Mr. Rumsfeld, Defense Department Briefing of 26 September 2002, 1:15 P.M.

world toward a greener, a less consumer-oriented society. That this might come at the expenses of developing countries developing less is, in the opinion of Lomborg, too easily discounted, and the IPCC is blamed for not making this side of the argument explicit. Hence another important element that analysts looking at scientific advice to policy should consider is the elucidation of agendas (value-laden divides) associated with the conflicting views.

An excellent example of the "neutral" nature of precautionary thinking (as opposed to it being a tool for environmentalism) is the review of the European Environment Agency's (EEA) report "Late Lessons form Early Warnings" (EEA 2001) published in *Nature* [12]. While the report presents an interesting collection of case studies from which a number of "Precautionary Principle lessons" can be learnt, Pielke argues that we should not learn only through cases where something went wrong in spite of signals that should have been used otherwise by the scientific community or decision-makers. We should also learn through those cases where nothing went wrong, or even by those cases where precaution was adopted disproportionately (with today's hindsight). Pielke concludes that the PP is of limited usefulness as a guide for action arguing that Bush's opposition to the Kyoto Protocol is also framed in precautionary terms.

Another example is the use of precautionary thinking to oppose the compulsory labeling of genetically-modified food, on the basis of the best interest of the consumer [13].

All this to make the point that the application of the PP would always be contentious. From GM food to electrosmog, from the Kyoto protocol on emission reduction to hormone growth meat, it is clear that:

- risk and cost benefit are only part of the picture;
- there is a plurality, often irreconcilable, of interests and perspectives;
- perspectives will be over hierarchies of dimensions, e.g., not only about energy or biodiversity or risk, but also about lifestyles and worldviews;
- there will be losers and winners in any way the balance tilts.

In the light of this analysis, one could require that a genuine use of the PP should avoid the common pitfall of lack of transparency. Then we would prevent the deception, perhaps even self-deception, of private interests (e.g., of a food multi-national) being dressed as ethical ones (saving the world from starvation), or vice versa, worldviews (a less consumer-oriented society) being sold via a climate-change scare. An example of lay people discarding such claims is found in PABE, a European-funded research project [14 and available from: http://www.pabe.net].

Finally, we should also mention the difficulty in implementing the principles of governance that underpin the PP. European Union (EU) institutions already suffer with a representativeness problem* when dealing with the EURO, with asylum policy or immigration issues, the same problem is faced when dealing with Kyoto or GMO. Given the centrality of uncertainty, our task is to articulate as consistently as possible an approach designed to evaluate the information used as input to the debate over the application of PP to a specific issue, in such a way as to allow the multidimensionality of perspectives to emerge as part of the process. This would avoid the lock-in situation generated if one tried to frame the discussion on a specific PP case after some decision has been made, or after the issue has been snatched away from society by specific organized stakeholders (industrial or multi-national, green or otherwise lobbies).

Furthermore, science, when used in support to decision making, must be an aid to the policy process, and should not render it more difficult by adding controversial inputs disguised as scientific facts (for instance, the case of the value-of-life in the climate change context). In this respect science in support to policy is different from the traditional scientific endeavor, where controversy and reciprocal falsification are the accepted rule.

In this context it is crucial to capture the widest spectrum of knowledge and inferences (including minority views) that can potentially concur with the formulation of EU policies [15]. This is part of what we call an "extended quality assurance process" that complements the tradi-

* When issues that impact on many are highjacked by a few.

tional peer review. Those involved in the decision are an "extended peer community", being part of the framing of the issue and co-producers of relevant knowledge.

The role of anticipatory research is also critical. Anticipatory research might produce alarms, sometimes scares, and the essence of the PP is that some of these call for action, even if the evidence is speculative or incomplete. At the same time, society should be protected by an excessive use of the PP, but even in this case we will have to choose not to act on the basis of incomplete information. This situation is that of a type I error (apply PP to a scare which then turns out to be false) or type II (inaction when the scare ends up being a real threat).

THE ROLE OF SCIENCE

It is no longer plausible to maintain that for any policy issue science will provide the unproblematic facts that determine the correct decision following the "modern" model of truth entailing the good. Rather, it is typical of our policy processes that facts are uncertain, values in dispute, stakes high and decisions urgent [2]. Recognizing the pervasiveness of scientific uncertainty, the European Commission has issued a Communication on the Precautionary Principle [16]. This modifies the "modern" model of relations between science and policy by introducing a meta-scientific principle allowing or requiring action by the authorities in order to protect health and the environment.

Policy issues (such as the creation of new GMOs) are particularly challenging for science, and this is a novel situation for decision makers. The previous relation between hard, objective scientific facts and soft, subjective value-judgements is now inverted. All too often, we must make hard policy decisions where our only scientific inputs are irremediably soft. In one sense risks and safety are in the domain of science: the phenomena of concern are located in the world of nature. Yet the tasks are totally different from those traditionally conceived by modern Western science. To engage in these new tasks we need new intellectual tools in order to deal effectively with uncertainty, complexity, a multiplicity of legitimate perspectives and value-loadings of all sorts.

Special caution must be used in the use of mathematical models as a way to explore formally the outcome of alternative courses of action. Models as heuristic tools designed for the regulatory appraisal of technological risk must be proven capable to deal with uncertainty. When possible, the model should incorporate the plurality of framing assumptions present in the debate. Not doing this results in studies appearing more factual and value-neutral than warranted.

Hence in the present work three elements are considered:

- merits and limits of the use of modeling;
- management of scientific uncertainty;
- use of precaution in the technological appraisal of risk.

While the first two issues have been mostly within the scientific community, the third one really lies at the boundary between science and policy or science and governance, in modern parlance. We focus on what benefits can be brought to the implementation of a precautionary approach by quantitative uncertainty and sensitivity analysis methods. We shall propose some heuristic tools aimed to increase the transparency of a precautionary approach debate. More specifically, we will consider how quantitative sensitivity analysis techniques can be used to decide upon the legitimacy of a precautionary approach in relation to conventional scientific and technological appraisal.

UNCERTAINTY IN THE SCIENTIFIC METHOD

Uncertainty is not an accident of the scientific method, but its substance. Peter Høeg [17], a Danish novelist, writes in "Borderliners":

"That is what we meant by science. That both question and answer are tied up with uncertainty, and that they are painful. But that there is no way around them. And that you hide nothing; instead, everything is brought out into the open".

How does uncertainty impact on the use of models as part of the scientific methods? Rosen's [18] formalization of the modeling activity (Fig. 6), argues that models are constructs built in the hope to mimic a natural system of interest (but the same applies to any kind of material system).

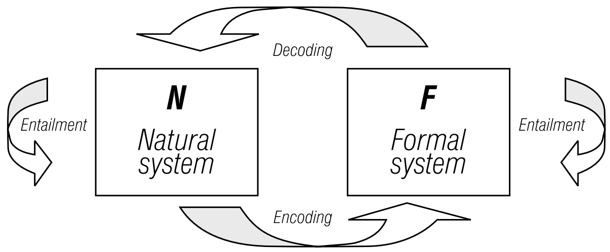

Fig. 6. Rosen's formulation of modeling activity [18].

We can understand the gap between the natural system and the construct by using Aristotle's categories of causation. The natural system is characterized by the material, efficient, and final causes (answering the questions: What is it made of?, How does it work? Why is it there?), the model is characterized only by the formal cause (answering what is its structure?). The link between the model (driven by a formal entailment structure) and the world (entailed by the classes of causality mentioned) is the process of "encoding" (from world to model) and "decoding" (from model to world). Encoding and decoding are not themselves "entailed" by anything, i.e., they are the object of the modelers craftsmanship. Yet those two activities are the essence and the purpose of the modeling process, i.e., one constructs a model in the hope that the decoding operation will provide insight into the world. This is only possible if the uncertainty in the information provided by the model (the substance of use for the decoding exercise) is carefully apportioned to the uncertainty associated with the encoding process.

What are the implications of adopting Rosen's epistemology?

1. The freedom of the modeler (and the resulting ambiguity) is accepted.

2. Models are different from straight physical laws (yes/no kind of questions).

It has been argued that often the complexity of models largely exceeds the requirements for which they are used, and this is also true for complication. Especially if one adopts Oreskes et al.' [4] viewpoint (models are heuristic constructs, built for a task), then they should not be more complex than they need to be. A model is then "relevant" when its input factors actually cause variation in the model response that is the object of the analysis [19]. Model "unrelevance" could flag a bad model, a model used out of context, or a model unable to provide the answer being sought. Excess complexity could also be used to silence or to fend off criticism from stakeholders (e.g., in environmental assessment studies), and should hence be avoided. Empirical model adequacy should be sought instead.

Oreskes et al. [4] argue that natural systems are never closed, and models put forward as descriptions of these are never unique. Hence, models can never be 'verified' or 'validated', but only 'confirmed' or 'corroborated' by the demonstration of agreement (non-contradiction) between observation and prediction. Since confirmation is inherently partial, models are qualified by a heuristic value: models are representations, useful for guiding further study, but not susceptible to proof. Moreover,

"Models can corroborate a hypothesis […]. Models can elucidate discrepancies with other models. Models can be used for sensitivity analysis – for exploring "what if" questions – thereby illuminating which aspects of the system are most in need of further study, and where more empirical data are most needed".

Models as heuristic tools designed for the regulatory appraisal of technological risk must be proven capable to deal with uncertainty. Especially when the model is used to drive a choice or a decision, the importance of the associated uncertainties should be quantified, and the relevance of the model ensured.

What are the implications of adopting Oreskes' viewpoint?

1. Especially when the model is used to advocate a practice, or to sustain a statement, it is more likely to play the role of generic evidence in a trial, whose weight must ultimately be established by a jury.

2. Corroboration is crucial. Not only must a model be shown not to contradict the evidence, but it must do so when all driving forces relevant to the problem have been incorporated in a way that is plausible to a community of evaluators.

Paraphrasing Oreskes, we might add that models of natural or man-made systems in regulatory appraisal are used to identify, accuse or absolve possible culprits.

As evident from the previous discussion, one might have to consider the existence of several models equally plausible

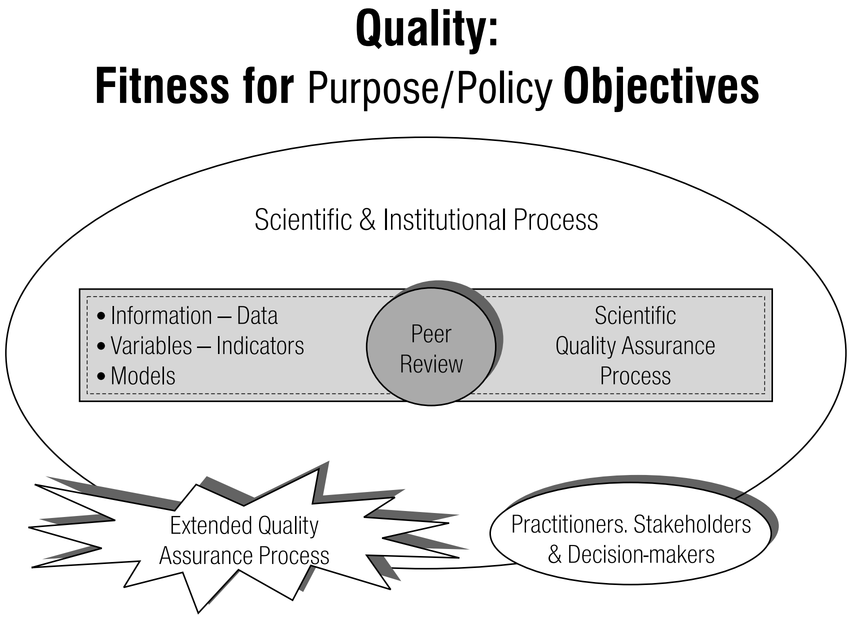

Fig. 7. Extended quality assurance process.

for a given system. The uncertainty arising from this source should be compounded with factor uncertainty. The assessor might even be confronted with alternative systems of indicators [20]. This also touches upon the so called "equifinality" problem. Equifinality is a term used by Beven [21] to refer to the problem that several models may be compatible with a given set of data. This is indeed a tautology, whenever one moves away from the restricted ambit of statistical model identification. In real systems, an unambiguous model identification would be the same as a model validation (declaring a model true), which few people now believe possible.

Often, the physical or technological worlds that are the subject of the analysis are not the only uncertain elements of the assessment. Lemons et al. [22] remind us of the importance of framing assumptions in modeling. Some of these assumptions reflect different value judgements and ethical principles of different constituencies or stakeholders. Not recognizing the "value laden" nature of the framing assumptions mentioned above, results in studies appearing "more factual and value-neutral than warranted". Along the same lines, it is argued that in health and environmental evaluations, the assessors and the stakeholders are themselves part of the knowledge production systems, and should be included in the evaluation as part of an extended quality assurance process (Fig. 7).

This falls under the heading "Post-Normal Science" [23], which considers the environment as a site of conflict between competing values and interests and different groups and communities that represent them. Power relations, hidden interests, cultural constraints, and other "soft" values, are relevant and unavoidable variables that must be considered explicitly, as they heavily but not deterministically affect the possible outcomes of the strategies to be adopted.

An example of how the debate on the use of alternative models might easily become polarized is when one constituency accuses another of instrumental use of models. This may happen typically when models are used to justify decisions with a great social and economic impact. Thus, it is not surprising to find sceptical opinions about the modeling enterprise.

An example is provided by *The Economist* [24], where one reads that:

"... based largely on an economic model […] completing K2R4 [a nuclear reactor] in 2002 has a 50% chance of being <least cost>."

Given that the model was used to contradict a panel of experts on the opportunity to build the aforementioned reactor, *The Economist* comments:

"Cynics say that models can be made to conclude anything provided that suitable assumptions are fed into them".

It would be highly instructive to look at what factors were determining the variation around the “least cost” region. The outcome of this analysis could then provide experts with additional insight.

About 20 years earlier, Hornberger and Spear [25] had noted: “… most simulation models will be complex, with many parameters, state-variables and non linear relations. Under the best circumstances, such models have many degrees of freedom and, with judicious fiddling, can be made to produce virtually any desired behavior, often with both plausible structure and parameter values”.

PRECAUTIONARY THINKING

Risk is a dominant feature of our society. Political conflict and distributional tension are today about risk and its distribution as much as about wealth, cultural or educational inequalities. Examples of polarized debate about risk are not difficult to identify: Bovine Spongiform Encephalopathy (BSE), Brent Spar, GMO, hormone growth beef, endocrine disruptors and chemicals in general.

Yet decisions are to be made in a context of irreducible uncertainty. Here, sound, defensible and participated policies are as important as calls for sound science. This is the background of the Precautionary Principle. Central to the PP are issues such as:

- the under-determinacy of scientific discourse before the complexity of hazards;
- the multidimensionality of risk;
- the incommensurability of risk components;
- the need for broad-based appraisal, including a plurality of social perspectives and options, weighting both costs and benefits or “pros” and “cons” (as called in the above mentioned EEA’s report);
- the existence of ignorance as distinguished from uncertainty.

According to Stirling [3], both “sound science” and “precaution” identify similar responses when confronted with regulatory appraisal. Among these:

“Express appraisal results not as single discrete numerical values, but using sensitivity analysis systematically to “map” the consequences of different value judgements and framing assumptions.

Prioritize then qualities of transparency and simplicity in selecting appraisal methods and provide for effective extended peer reviews.”

Uncertainty encountered in the regulation of technological risk calls for appropriately applied quantitative methods, especially when the PP is invoked. More to the point, uncertainty and sensitivity analysis should also be invoked to decide whether the issue at hand calls for a precautionary approach.

A variety of actors and perspectives are today to be reckoned with, in any field where choices exist relevant to a plurality of stakeholders, and where asymmetries in costs and benefits exist. This also impinges on the crucial issue of trust. Paradoxically, trust in science and governance is “more vulnerable in literate, sophisticated societies, where citizens are able to assess the quality of the performance of their institutions” [19].

Today this new way of thinking about risk appraisal is being encoded within the PP. This should not be confused with the precaution already and routinely exercised in the practice of risk regulation. The PP calls for the explicit expression of the impact of different value judgements and problem-framing assumptions. Seen from a PP perspective, risk is no longer reducible to a single metric, but is in fact a multidimensional object; risk can be measured against environment, health, economy, etc. In turn, environmental risk may concern biodiversity, chemical use, genetic pollution, wildlife effects, visual, or esthetic effects. Given that some of these attributes are irreducibly qualitative, an incommensurability problem is also present [3].

QUANTITATIVE ANALYSIS OF UNCERTAINTY AND SENSITIVITY

Quantitative uncertainty and sensitivity analysis techniques [26,27] could provide an increased transparency in the use of scientific information, with a potential relevance to the participatory approaches advocated in Post-Normal Science. In particular, these techniques could give nonprescriptive guidance in the application of a precautionary approach. We offer here two possible uses of these methods.

Transparency and relevance also discussed by Beck et al. [19] would be achieved by a process of model simplification whose objective is ultimately to tune the degree of complexity of the model to the questions being put to it. The stakeholders should hence be confronted with the set of relevant inputs (with their uncertainty), models, and predictions. Relevant, here, would mean, "proven to be relevant via a rigorous quantitative sensitivity analysis". The techniques that might be used to this end are the so called "variance-based methods". These techniques aim to decompose the variance of a model output Y according to source reviewed in [7], while Table 1 offers a summary description. Clearly, not all experts will agree that their model could or should be simplified for the purpose of debate within a participatory framework. On the other hand, all complexity that cannot be resolved and made explicit is automatically removed from debate and negotiation. Models used by IPCC may be too complex for meaningful simplification, but even in this case, when the assumptions underlying these models and scenarios are made explicit, then the debate becomes profitable.

AN INTEGRATED APPROACH

A second application that we suggest is the one already outlined in the first section, and could be seen as a complement to the pedigree-based methods developed in Post-Normal Science. One idea that was preliminarily considered with our colleagues at RIVM (the Netherland Environmental Assessment Agency) is that one plots on a bi-dimensional diagram quality measures and sensitivity measures. The plots would collect all the elements that concur with a decision, giving for each element its quality and its "sensitivity" interpreted as impact on the decision. In this way "soft" and quantitative measures would be combined (see www.nusap.net for more information about the method).

This application could be seen as part of the development of an integrated approach that we are deploying. The approach takes into account a new awareness about the role of knowledge in society and the emerging context of science and governance.

It starts from a not well-defined policy issue through its transformation into technical problems (framings), policy options, and assumptions. It couples the different levels of an issue (societal, institutional, and scientific) with

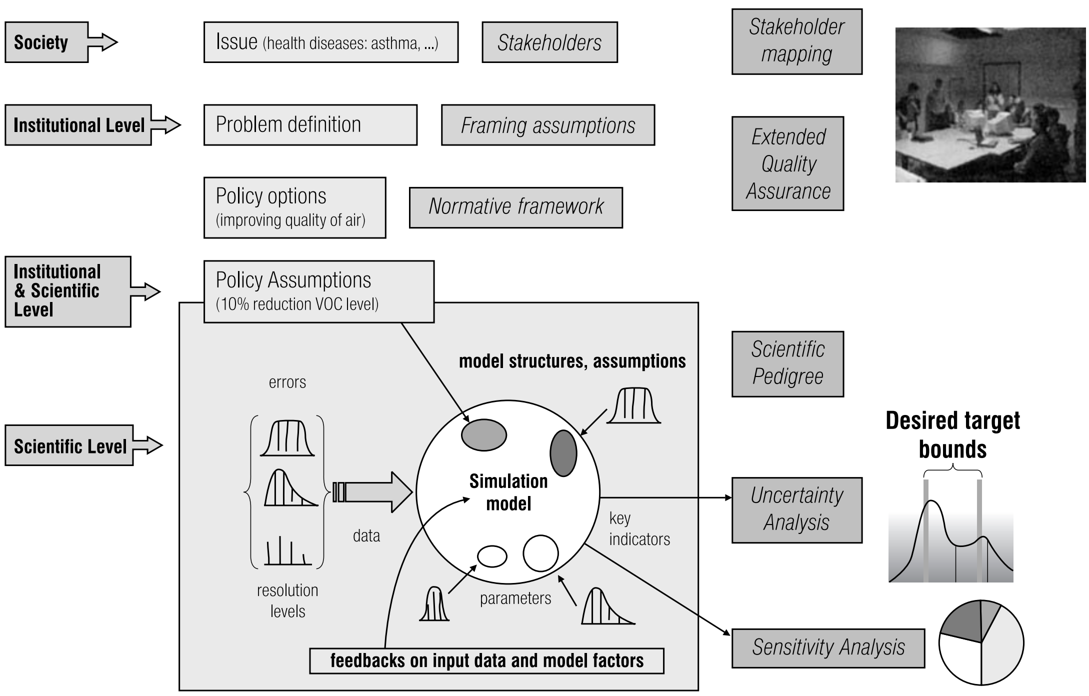

Fig. 8. Integrated approach.

appropriate methods and actors, combining formal (e.g., sensitivity, muti-criteria) and informal (e.g., participatory) methods, and quantitative and qualitative representations (Fig. 8).

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