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Knowledge Quality Assessment
tools for reflective science

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Diagnosis

Two dominant strategies:
uncertainties are either

- **downplayed** to promote political decisions (enforced consensus), or
- **overemphasised** to prevent political action

- Both promote decision strategies that are **not fit for meeting the challenges** posed by the uncertainties and complexities faced.

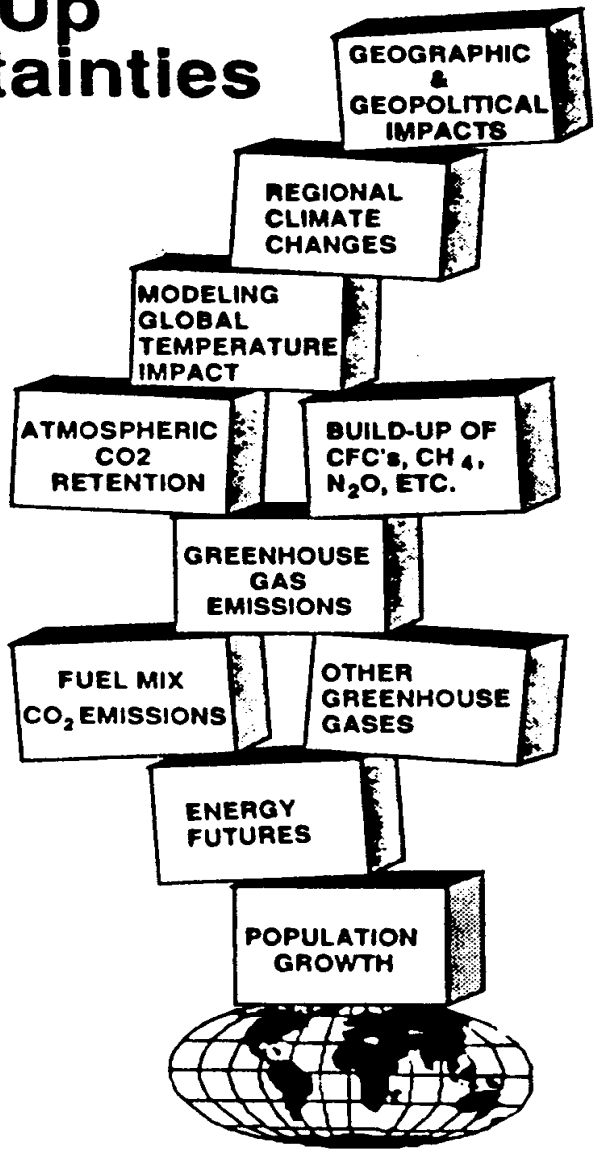
- This delays a transition to sustainability.

- We need a theory of uncertainty, **scientific dissent & plurality** in sustainability science.

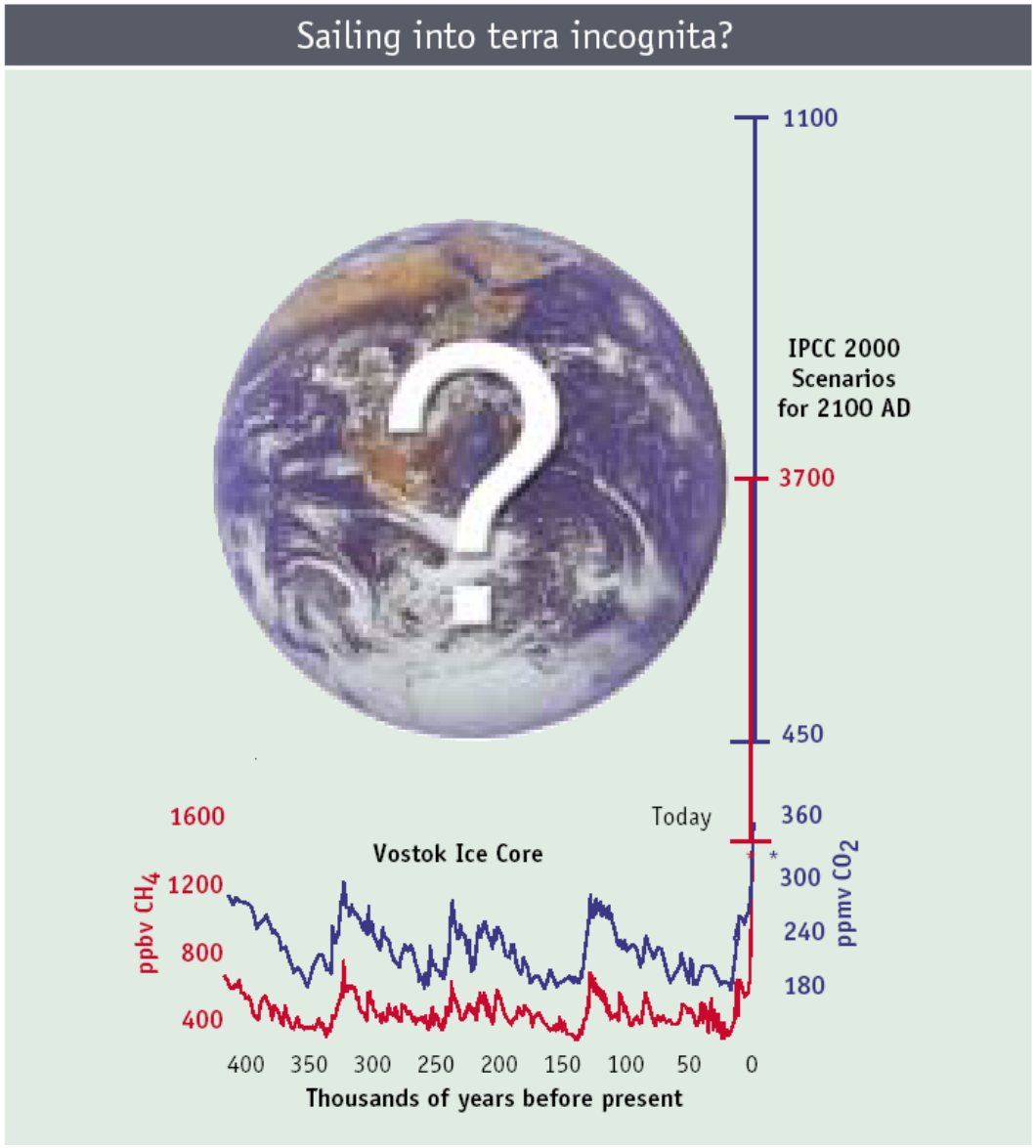
Examples of framings of uncertainty I

GLOBAL CLIMATE CHANGE

Piling Up Uncertainties



Examples of framings of uncertainty II: Terra Incognita



Atmospheric concentrations of the greenhouse gases CO_2 and CH_4 over the last four glacial-interglacial cycles from the Vostok ice core record. The present-day values and estimates for the year 2100 are also shown.

Adapted from Petit et al. (1999) Nature 399, 429-436 and the IPCC (Intergovernmental Panel on Climate Change) Third Assessment Report by the PAGES (Past Global Changes) International Project Office.

A practical problem:

Protecting a strategic fresh-water resource

5 scientific consultants addressed same question:

"which parts of this area are most vulnerable to nitrate pollution and need to be protected?"

(Refsgaard, Van der Sluijs et al, 2006)

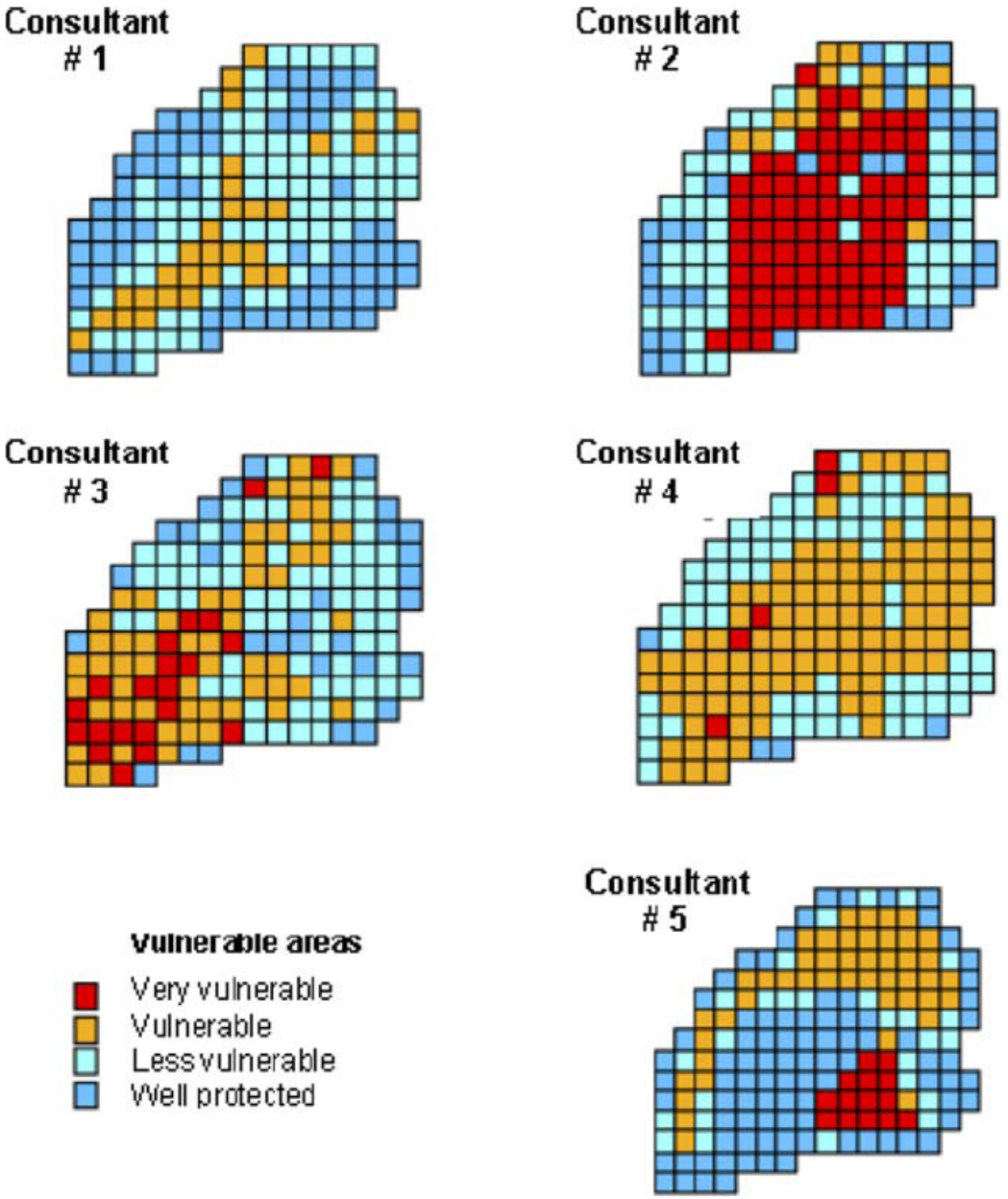


Fig. 1. Model predictions on aquifer vulnerability towards nitrate pollution for a 175 km^2 area west of Copenhagen [11].

3 framings of uncertainty (Van der Sluijs, 2006)

'deficit view'

- Uncertainty is provisional
- Reduce uncertainty, make ever more complex models
- *Tools:* quantification, Monte Carlo, Bayesian belief networks

'evidence evaluation view'

- Comparative evaluations of research results
- *Tools:* Scientific consensus building; multi disciplinary expert panels
- focus on robust findings

'complex systems view'

- Uncertainty is intrinsic to complex systems: permanent
- Uncertainty can be result of new ways of knowledge production
- Acknowledge that not all uncertainties can be quantified
- Openly deal with deeper dimensions of uncertainty
- *Tools:* Knowledge Quality Assessment

"*speaking truth to power*" vs "working deliberatively within imperfections"

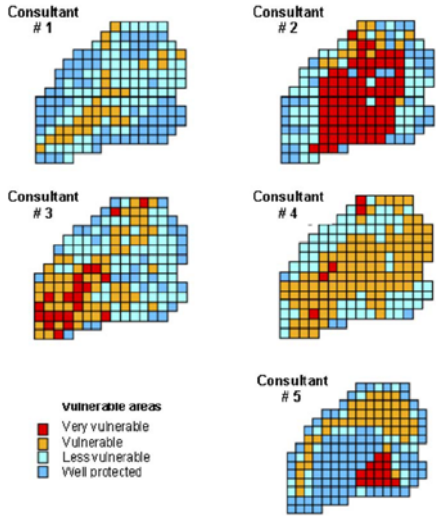
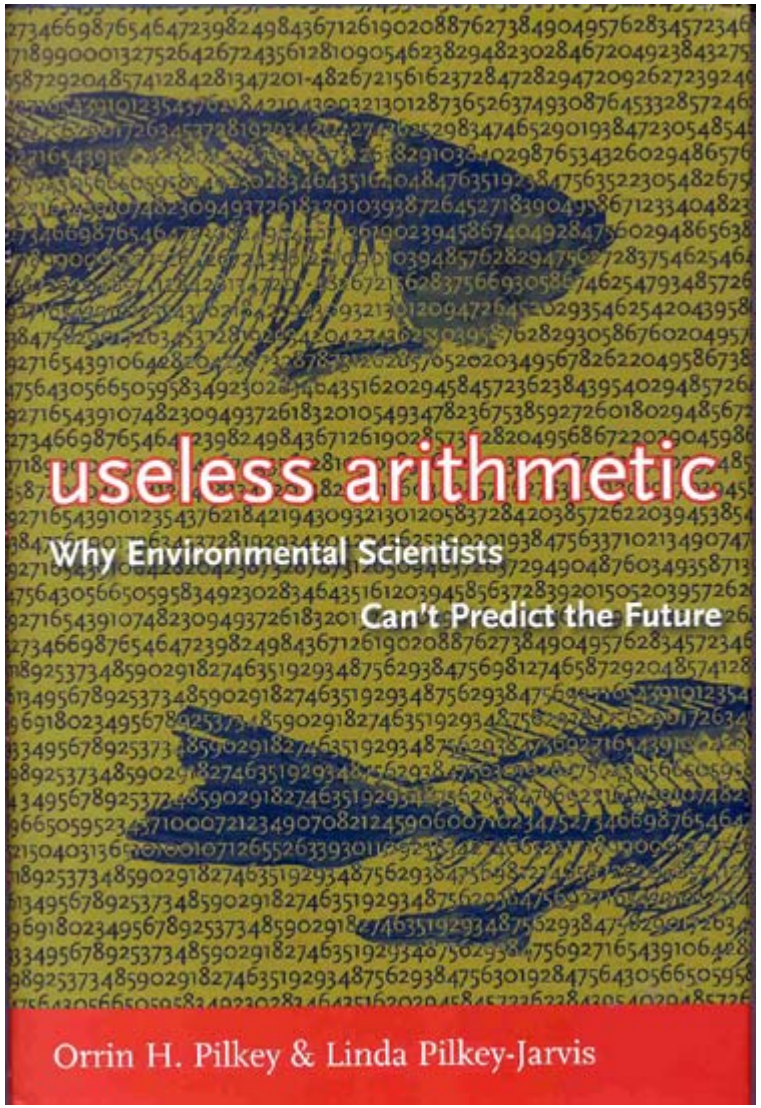


Fig. 1. Model predictions on aquifer vulnerability towards nitrate pollution for a 175 km^2 area west of Copenhagen [11].

How to act upon such uncertainty?

- Bayesian approach: 5 priors. Average and update likelihood of each grid-cell being red with data (but oooops, there is no data and we need decisions now)
- IPCC approach: Lock the 5 consultants up in a room and don't release them before they have consensus
- Nihilist approach: Dump the science and decide on an other basis
- Precautionary robustness approach: protect all grid-cells
- Academic bureaucrat approach: Weigh by citation index (or H-index) of consultant.
- Select the consultant that you trust most
- Real life approach: Select the consultant that best fits your policy agenda
- Post normal: explore the relevance of our ignorance: working deliberatively within imperfections

Pilkey & Pilkey, 2007 book



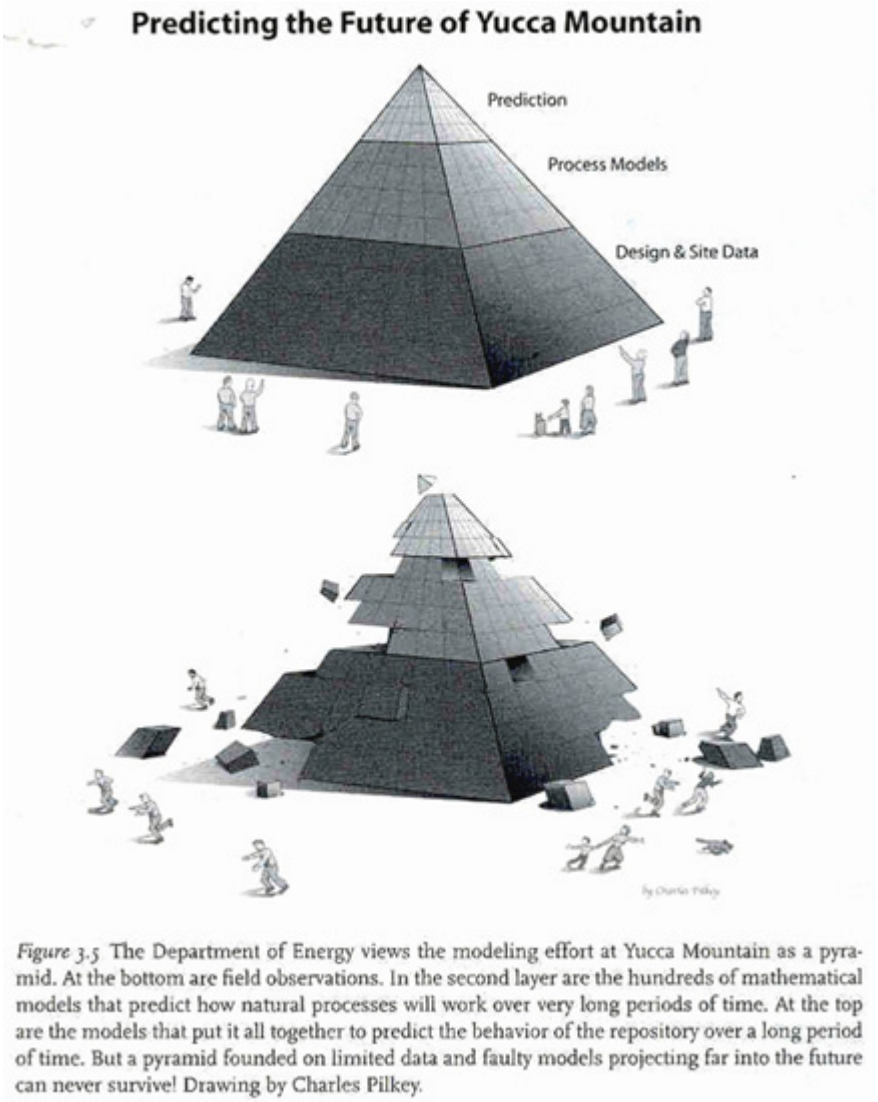


Figure 3.5 The Department of Energy views the modeling effort at Yucca Mountain as a pyramid. At the bottom are field observations. In the second layer are the hundreds of mathematical models that predict how natural processes will work over very long periods of time. At the top are the models that put it all together to predict the behavior of the repository over a long period of time. But a pyramid founded on limited data and faulty models projecting far into the future can never survive! Drawing by Charles Pilkey.

Yucca Mountain: bizarre mismatch

Regulatory standard implied need for scientific certainty for up to one million years

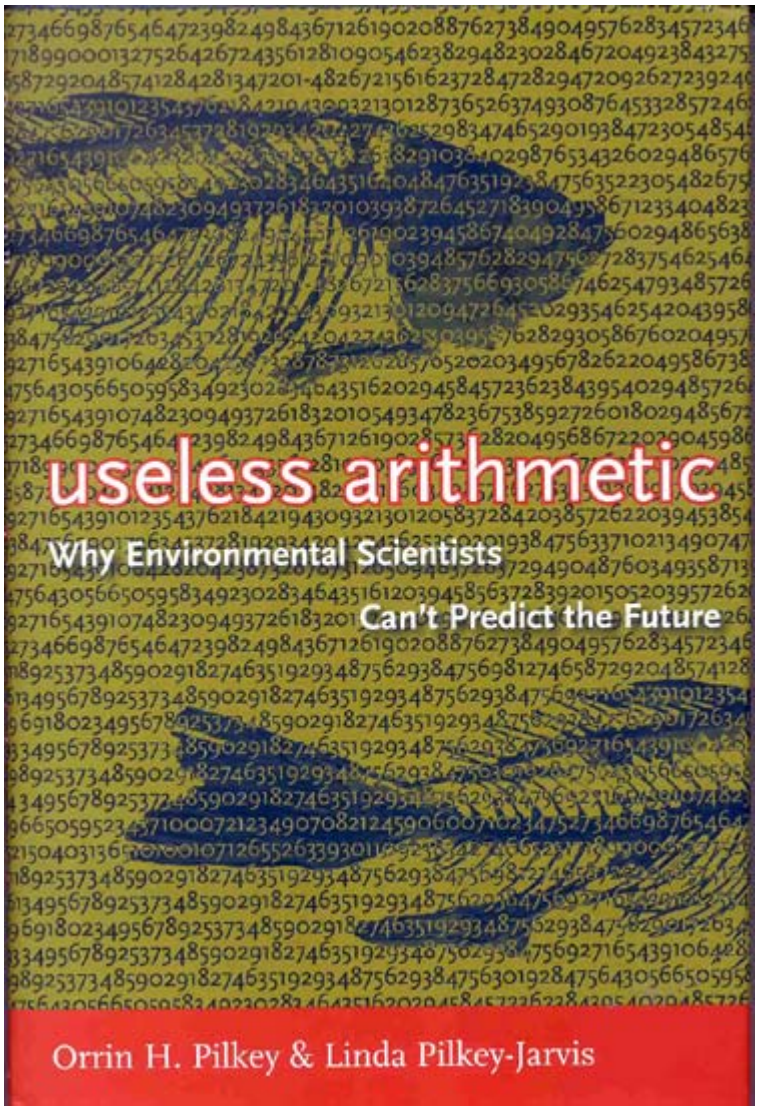
- **State of knowledge**
  - limitations of a quantitative modeling approach *(US-DOE's Total System Performance Assessment, TSPA)*
  - radical uncertainty and ignorance
  - uncontrolled conditions of very long term unknown and indeterminate future.

Ignorance:

Percolation flux: TSPA model assumed 0.5 mm per year (expert guess)

Elevated levels of Chlorine-36 isotope in faults uncovered by tunnel boring: percolation flux > 3000 mm per year over the past 50 yr...

Pilkey & Pilkey, 2007 book



Mathematical fishing

Two categories of Models in fish management

1. <u>Modeling blindfolded</u>: non-biologists or biologists deeply ensconced in the political system

-> politically acceptable optimistic answer

-> Uncertainties are hidden

2. <u>Models as "*Fig Leaves, Shields and Clubs*"</u>

-> something to hide behind

-> device to create unchallengeable authority

-> insulator: protecting agency scientists and fishery managers from attack by politicians who want to please unhappy fisherman

'The use of a model to reduce fishing pressure on a species – even if model is wrong – is better than the alternative of just an expert opinion that can be refuted by an other expert'

Science for sale

Industry groups are fighting government regulation by fomenting scientific uncertainty

DOUBT Is Their Product

By David Michaels
Photographs by Mindy Jones

Few scientific challenges are more complex than understanding the health risks of a chemical or drug. Investigators cannot feed toxic compounds to people to see what doses cause cancer. Instead laboratory researchers rely on animal tests, and vinyl chloride, chromium, benzene, benzidine, nickel, and a long list of other toxic chemicals and medications. What is more, Congress and the administration of President George W. Bush have encouraged such tactics by making it easier for private groups to challenge government-funded research. At

- Fabrication (and politicisation) of uncertainty

The example of the US Data quality act and of the OMB "Peer Review and Information Quality" which

"seemed designed to maximize the ability of corporate interests to manufacture and magnify scientific uncertainty".

Science for sale – Bisphenol A

Congress: Science for Sale?

Congress Launches Probe Into Firm's Work on Chemical Used to Make Many Plastic Bottles

*..a confidential Weinberg Group document ...in which the firm suggested to DuPont ... several ways it could **help "shape the debate"** about one of its chemical products. The firm proposed ... "**constructing a study to establish" that DuPont's chemical was safe**, and arranging the publication of papers "dispelling the alleged nexus" between the company's chemical and its alleged harmful effects on humans."*

ABC News 6 Feb 2008

Exclusive:
'Science for Sale' Probe Deepens

A scientific consulting firm once crowed of its success in delaying the cancellation of a harmful drug by 10 years, congressional investigators say.
Lawmakers have more tough questions for the Weinberg Group, which has been accused of "manufacturing uncertainty“ about research to benefit its corporate clients and their products.

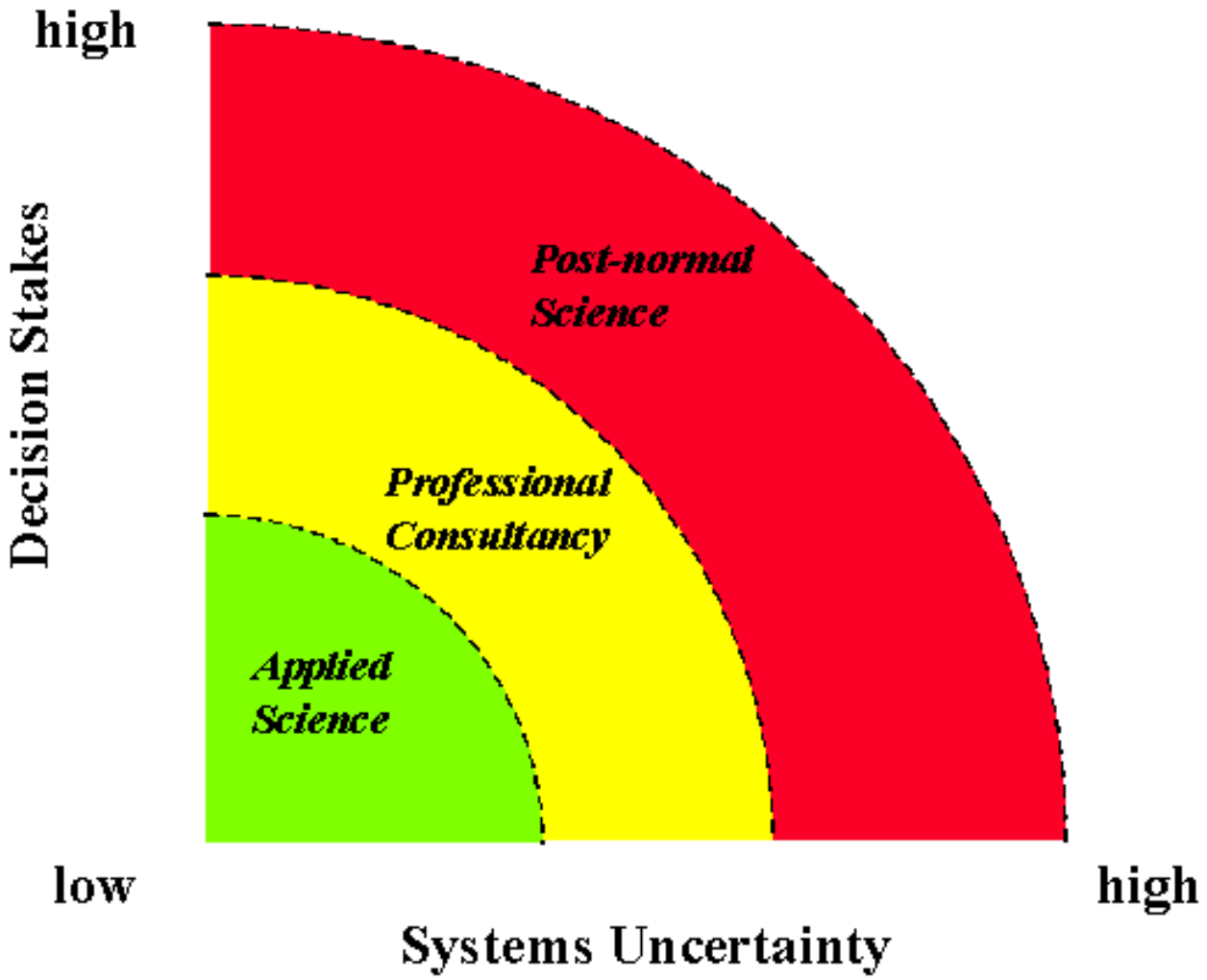
ABCNews, March 11, 2008,

Complex - *uncertain* - risks

Typical characteristics (Funtowicz & Ravetz):

- Decisions will need to be made before conclusive scientific evidence is available;
- Potential impacts of 'wrong' decisions can be huge
- Values are in dispute
- Knowledge base is characterized by large (partly irreducible, largely unquantifiable) uncertainties, multi-causality, knowledge gaps, and imperfect understanding;
- More research ≠ less uncertainty; unforeseen complexities!
- Assessment dominated by models, scenarios, assumptions, extrapolations
- Many (hidden) value loadings reside in problem frames, indicators chosen, assumptions made

Knowledge Quality Assessment is essential



Funtowicz and Ravetz, Science for the Post Normal age, *Futures*, 1993

Post Normal Science

Extended participation:

working deliberatively within imperfections

- Science (the activity of technical experts) is only one part of relevant **evidence**
- Critical dialogue on strength and relevance of evidence
- Interpretation of evidence and attribution of policy meaning to a given body of evidence is democratized
- Tools for Knowledge Quality Assessment empower all stakeholders to engage in this deliberative process

(Funtowicz, 2006; Funtowicz & 2007)

RIVM / De Kwaadsteniet (1999)

"RIVM over-exact prognoses based on virtual reality of computer models"

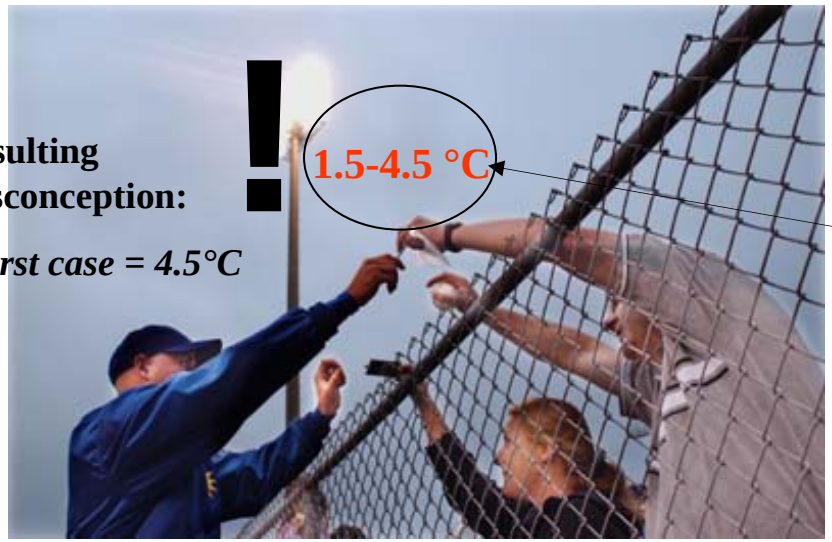
Newspaper headlines:

- Environmental institute lies and deceits
- Fuss in parliament after criticism on environmental numbers
- The bankruptcy of the environmental numbers
- Society has a right on fair information, RIVM does not provide it

Crossing the disciplinary boundaries

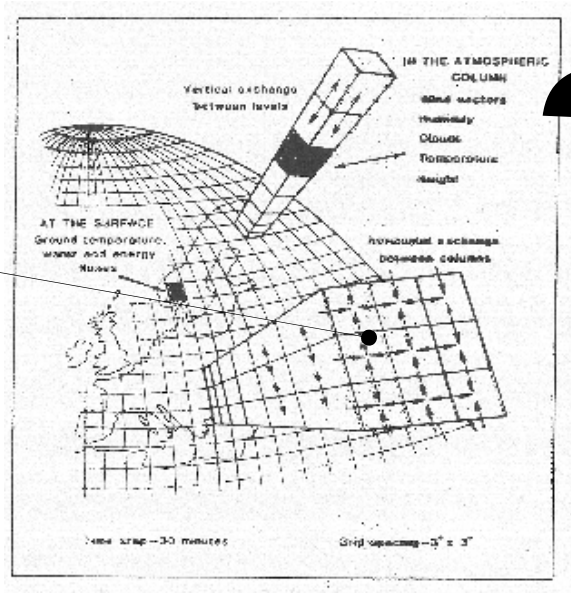
Once environmental numbers are thrown over the disciplinary fence, important caveats tend to be ignored, uncertainties compressed and numbers used at face value

e.g. **Climate Sensitivity**, see Van der Sluijs, Wynne, Shackley, 1998:



Resulting misconception:

Worst case = 4.5°C

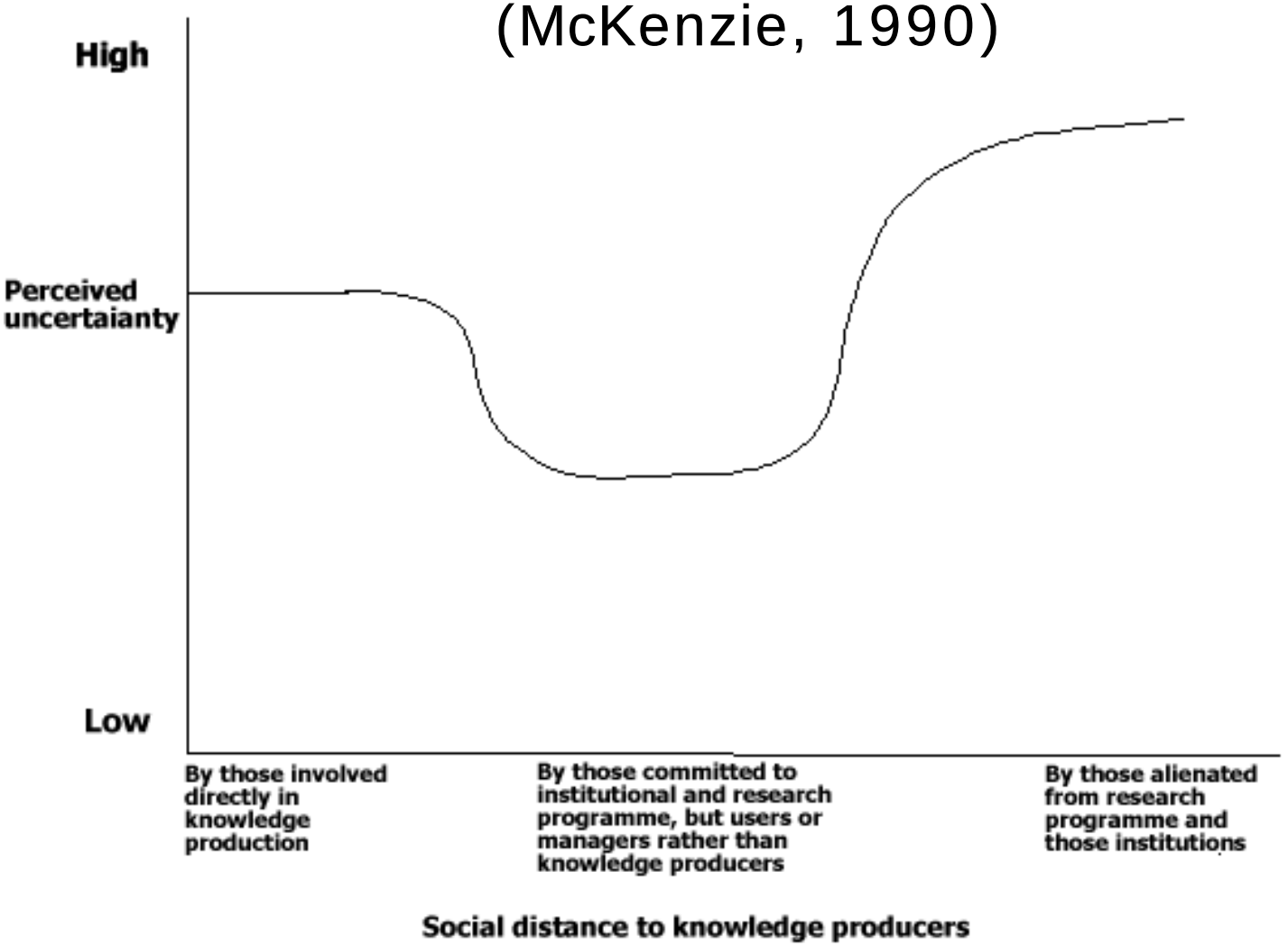


?

Former chairman IPCC on objective to reduce climate uncertainties:

- "*We cannot be certain that this can be achieved easily and we do know it will take time. Since a fundamentally chaotic climate system is predictable only to a certain degree, our research achievements will always remain uncertain.* ***Exploring the significance and characteristics of this uncertainty is a fundamental challenge to the scientific community.***" (Bolin, 1994)

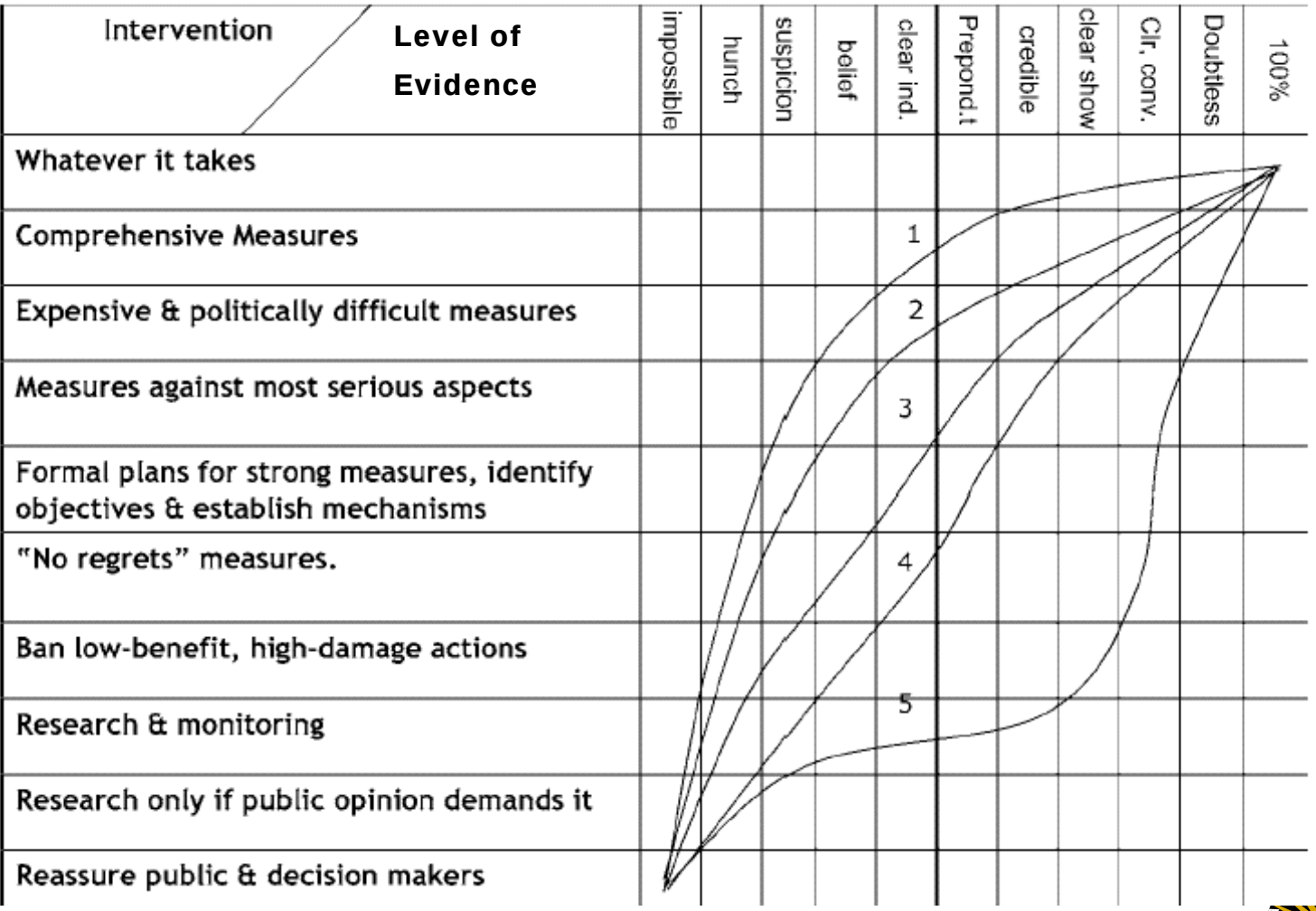
The certainty trough (McKenzie, 1990)



Weiss 2003/2006 evidence scale

10. Virtually certain
9. Beyond a reasonable doubt
8. Clear and Convincing Evidence
7. Clear Showing
6. Substantial and credible evidence
5. Preponderance of the Evidence
4. Clear indication
3. Probable cause: reasonable grounds for belief
2. Reasonable, articulable grounds for suspicion
1. No reasonable grounds for suspicion
0. Insufficient even to support a hunch or conjecture

Even where there is agreement on "level of evidence", there usually is substantial societal disagreement on what level of intervention is justified.



Attitudes according to Weiss 2003:

1. Environmental absolutist

2. Cautious environmentalist

3. Environmental centrist

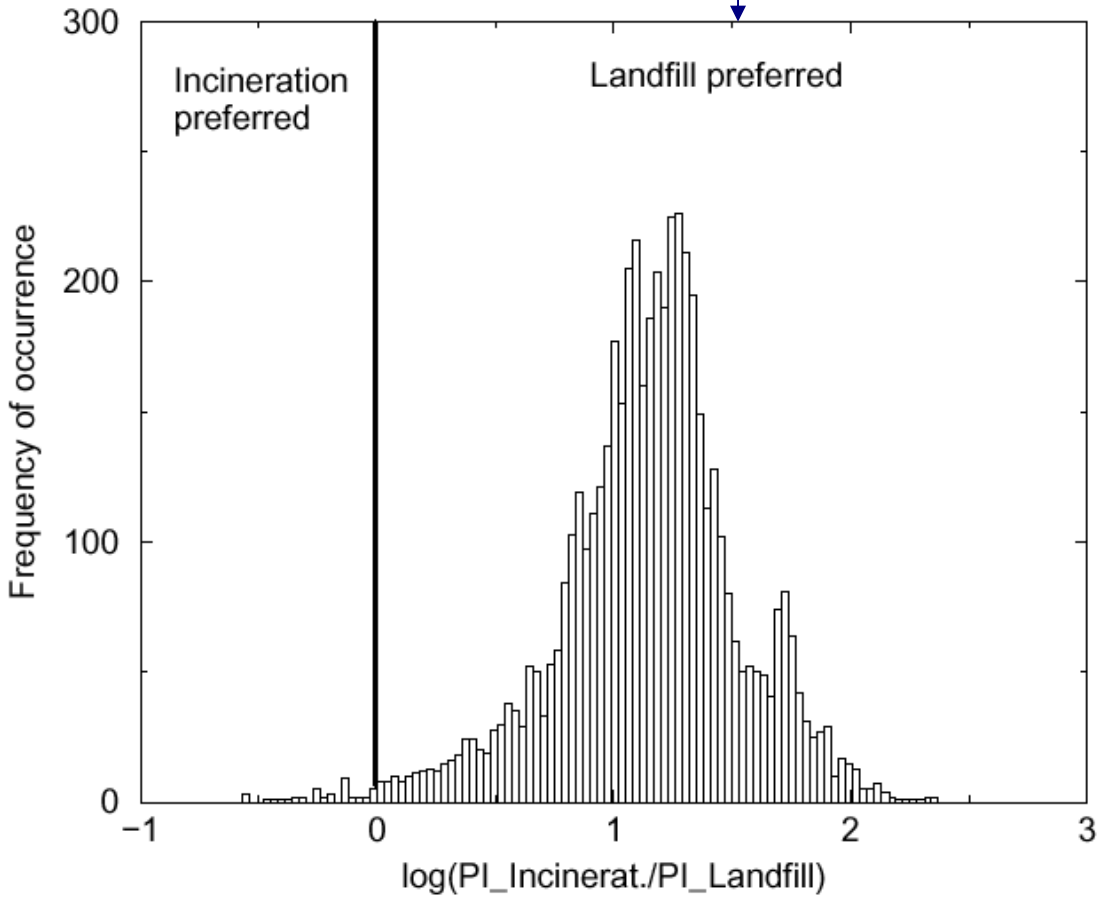
4. Technological optimist

5. Scientific absolutist

Insights on uncertainty

- More research tends to increase uncertainty
  - reveals unforeseen complexities
  - Complex systems exhibit irreducible uncertainty (intrinsic or practically)
- Omitting uncertainty management can lead to scandals, crisis and loss of trust in science and institutions
- In many complex problems unquantifiable uncertainties dominate the quantifiable uncertainty
- High quality $\neq$ low uncertainty
- Quality relates to **fitness for function** (robustness, PP)
- Shift in focus needed from reducing uncertainty towards reflective methods to explicitly cope with uncertainty and quality

High uncertainty is not the same as low quality!

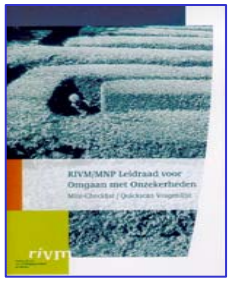


(slide borrowed from Andrea Saltelli)

RIVM-MNP Uncertainty Guidance

Reminder list
Invokes Reflection
Portal to QS

Mini-Checklist



Quickscan Questionnaire

Further Guidance
Advice
Hints & Implications

Quickscan Hints & Actions List

Tool Catalogue for Uncertainty Assessment

Detailed Guidance

Advice on Quantitative + Qualitative tools for UA

PNS in practice:

Tools & checklists for Knowledge Quality Assessment

RIVM/MNP Guidance for Uncertainty Assessment and Communication

rivm

MINI-CHECK	ELABORATION
1. Problem Framing	
In our assessment we pay attention to: (i) existing views on the problem other than the client's (including our own view), (ii) the interwovenness with other problems, (iii) possibly relevant aspects of the problem that are not dealt with in the research questions, (iv) the role the study is expected to play in the policy process, and (v) the way the study connects to previous studies on the subject.	*Indicate whether elaboration is or is not required and why (possibly for specific parts). If it is required, then go to Quickscan question 1.*
Wholly / Partly / Insufficiently	
2. Involvement of Stakeholders	
We have a clear picture of: (i) the relevant stakeholders, (ii) their views and roles with respect to the problem, and (iii) the problem aspects about which they disagree. On the basis of all this, we have decided *if*, *how* (in formulating research questions, contributing information/data, evaluating findings/results), and *when* (in the beginning, during, after) we should involve *which* stakeholders in this assessment.	*Indicate whether elaboration is or is not required and why (possibly for specific parts). If it is required, then go to Quickscan question 2.*
Wholly / Partly / Insufficiently	
3. Selection of Indicators	
We can provide adequate backing for the selection of indicators and their mutual relationships, we have considered alternative indicators, and in our report we discuss the limitations of the use of these indicators for this problem; we know the level of support among scientists and within society (including decision makers/politicians) for the use of these indicators.	*Indicate whether elaboration is or is not required and why (possibly for specific parts). If it is required, then go to Quickscan question 3.*
Wholly / Partly / Insufficiently	

■ The position reflects the level of knowledge

Level of knowledge	low	high
NH3 emission		
Modelability		
Empirical basis		
Theoretical understanding		
VOC emission from paint		
Modelability		
Empirical basis		
Theoretical understanding		
PM10 emission		
Modelability		
Empirical basis		
Theoretical understanding		

***SCIENCE* VOL 316 13 APRIL 2007**

"Today, eight years on from the Dutch scandal, no one makes more strenuous efforts than does the Netherlands' RIVM to accommodate and cope with the uncertainties of environmental data and models, hence to achieve the greatest possible quality in generating environmental forecasts."

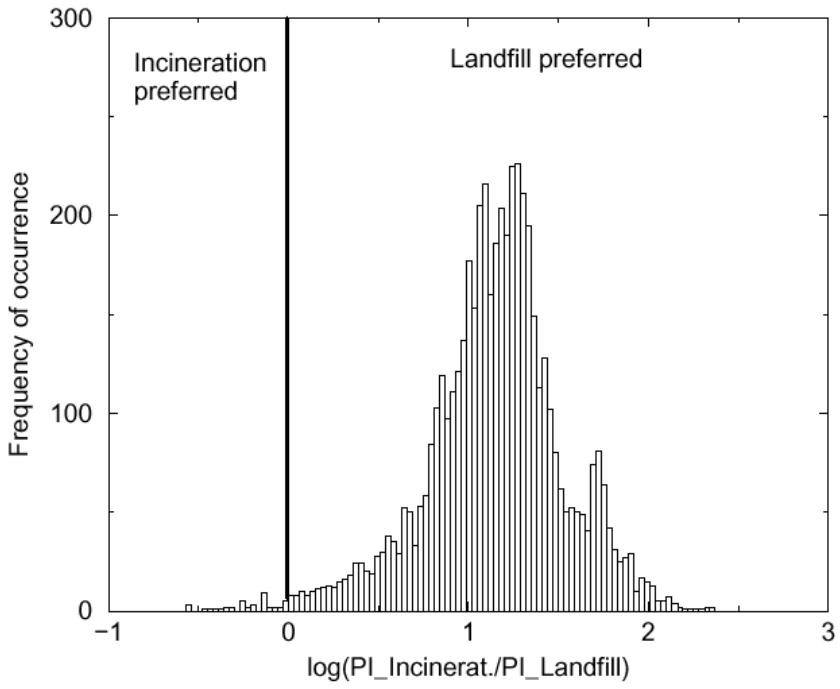
(Bruce Beck)

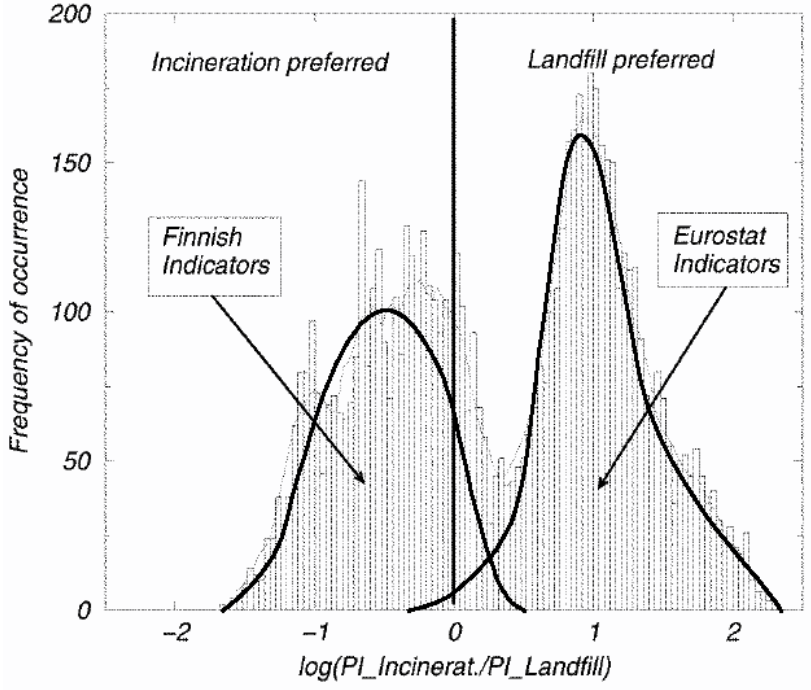
Foci and key issues in knowledge quality assessment (ref. 9)

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

High uncertainty is not the same as low quality,

but..... methodological uncertainty can de dominant





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UNCERTAINTY MATRIX		Level of uncertainty *(from determinism, through probability and possibility, to ignorance)*			Nature of uncertainty		Qualification of knowledge base (backing)			Value-ladenness of choices		
Location ↓		**Statistical uncertainty (range+ chance)**	**Scenario uncertainty (range as 'what-if' option)**	**Recognized ignorance**	**Knowledge-related uncertainty**	**Variability-related uncertainty**	**Weak** –	**Fair** 0	**Strong** +	**Small** –	**Medium** 0	**Large** +
Context	Ecological, technological, economic, social and political representation											
Expert judgement	Narratives; storylines; advices											
Model	**Model structure** Relations											
	Technical model Software & hardware implementation											
	Model parameters											
	Model inputs Input data; driving forces; input scenarios											
Data (in general sense)	Measurements; monitoring data; survey data											
Outputs	Indicators; statements											

Uncertainty tools

- Sensitivity Analysis
- Error propagation equations (TIER I)
- Monte Carlo analysis (TIER II)
- Expert Elicitation
- Scenario analysis
- NUSAP
- PRIMA
- Checklist model quality assistance
- Assumption analysis
- ……

Sensitivity analysis (SA)

SA is the study of

- The study of how the uncertainty in the output of a model (numerical or otherwise) can be apportioned to different sources of uncertainty in the model input
- how a given model depends upon the information fed into it

(Saltelli *et al.*, 2000).

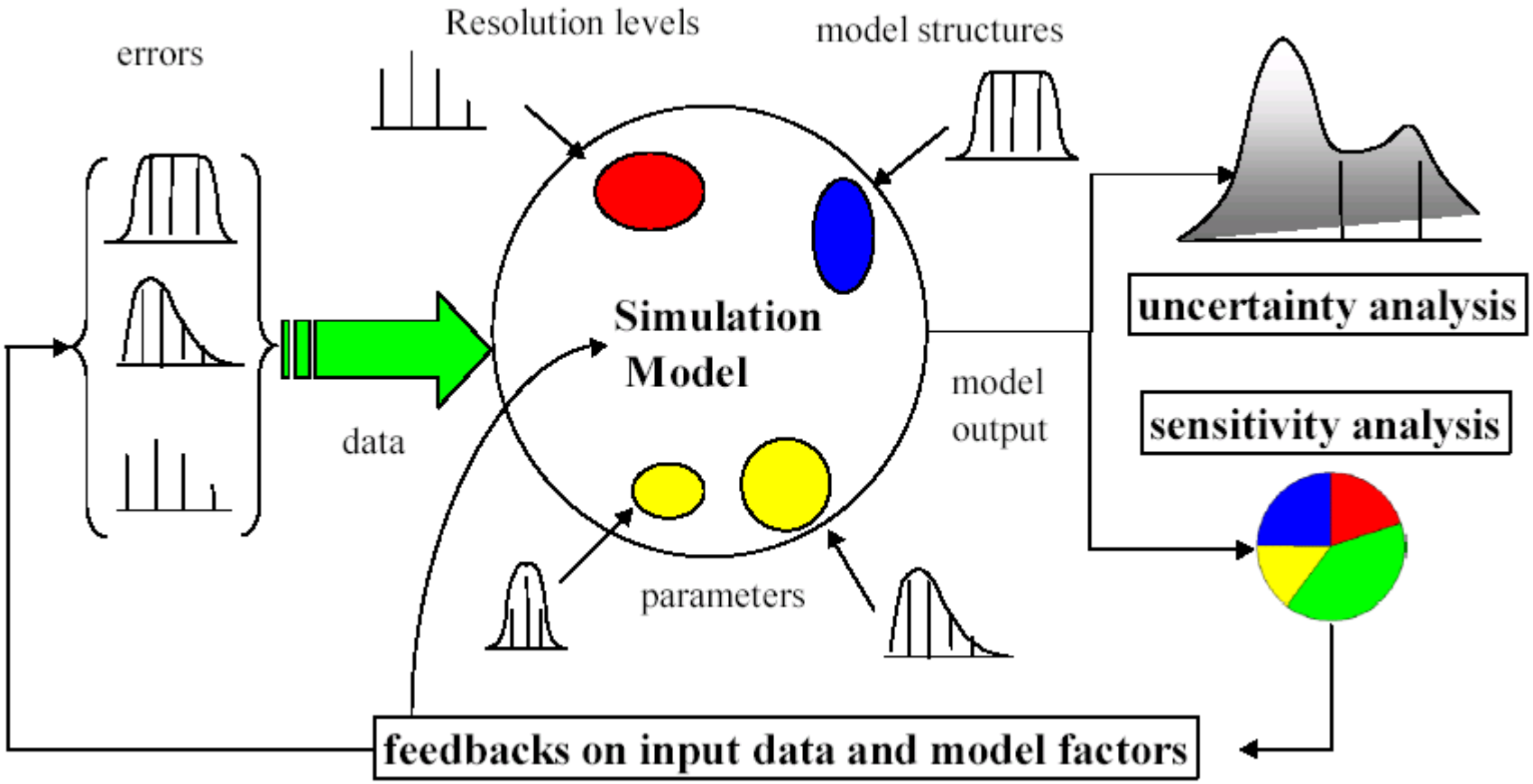
Sensitivity analysis

three types:

- Screening
- Local Sensitivity Analysis
  - Vary one parameter at a time over their range while keeping others at default value
  - Result: rate of change of the output relative to the rate of change of the input
- Global Sensitivity Analysis
  - Vary all parameters over their ranges (dependencies!)
  - Result: contribution of parameters to the variance in the output

Uncertainty analysis = Mapping assumptions onto inferences

Sensitivity analysis = The reverse process



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Do we know enough to quantify?

Risbey & Kandlikar (2007): What format is in accordance with the level of knowledge on the quantity?

- Full probability density function
  - Robust, well defended distribution
- Bounds
  - Well defended percentile bounds
- First order estimates
  - Order of magnitude assessment
- Expected sign or trend
  - Well defended trend expectation
- Ambiguous sign or trend
  - Equally plausible contrary trend expectations
- Effective ignorance
  - Lacking or weakly plausible expectations

Casman et al. 1999:

Mixed levels of uncertainty

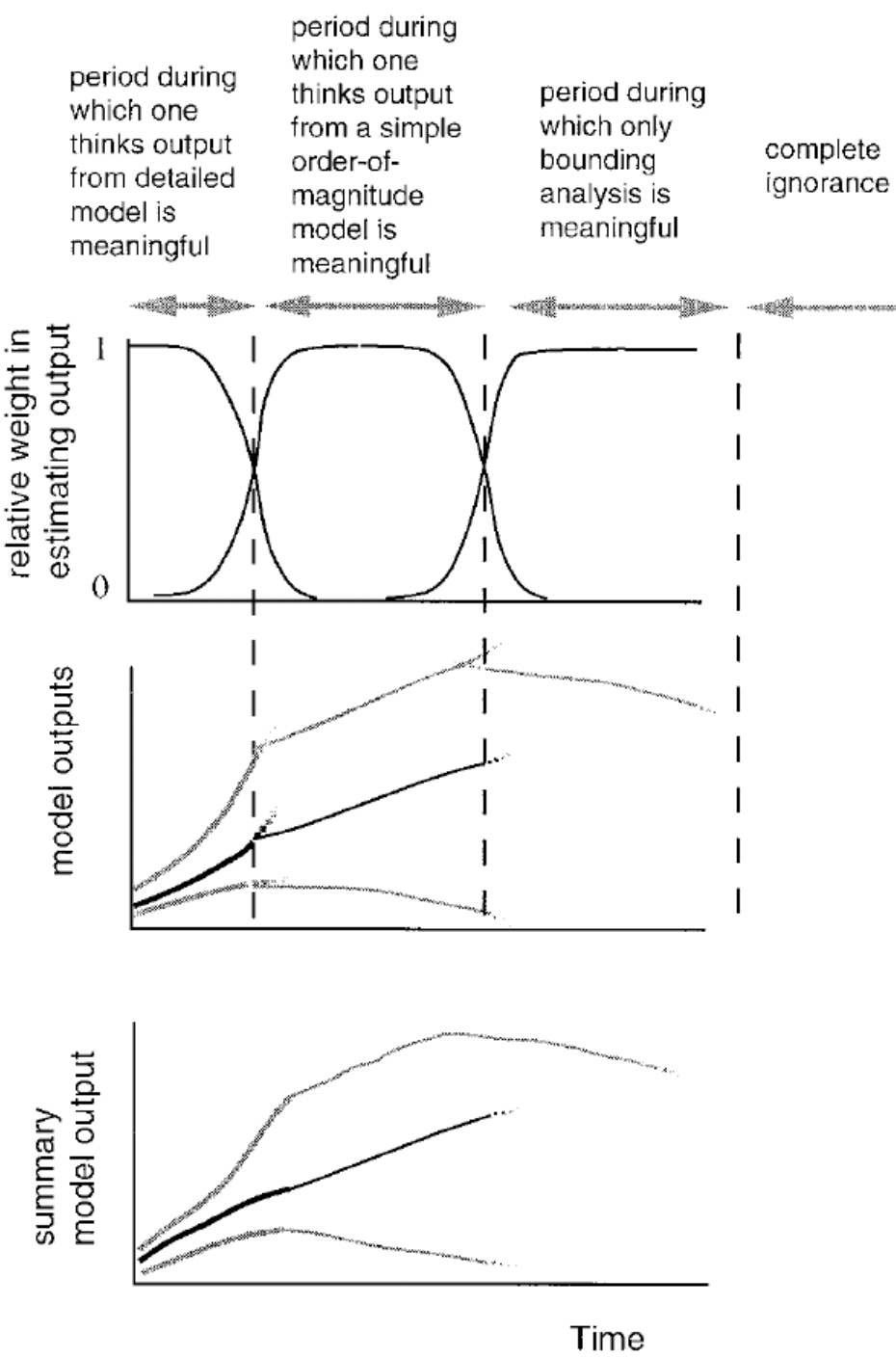


Fig. 3. Schematic illustration of the strategy of switching to progressively simpler models as one moves into less well understood regions of the problem phase space, in this case, over time. One starts with a detailed model that is likely to only be reliable for a few years. Gradually one moves over to a much simpler model based on order of magnitude considerations. Finally, in the long term, one can only bound the result, without giving best estimates.

Risk Analysis, 1999, **19** (1), 33-42

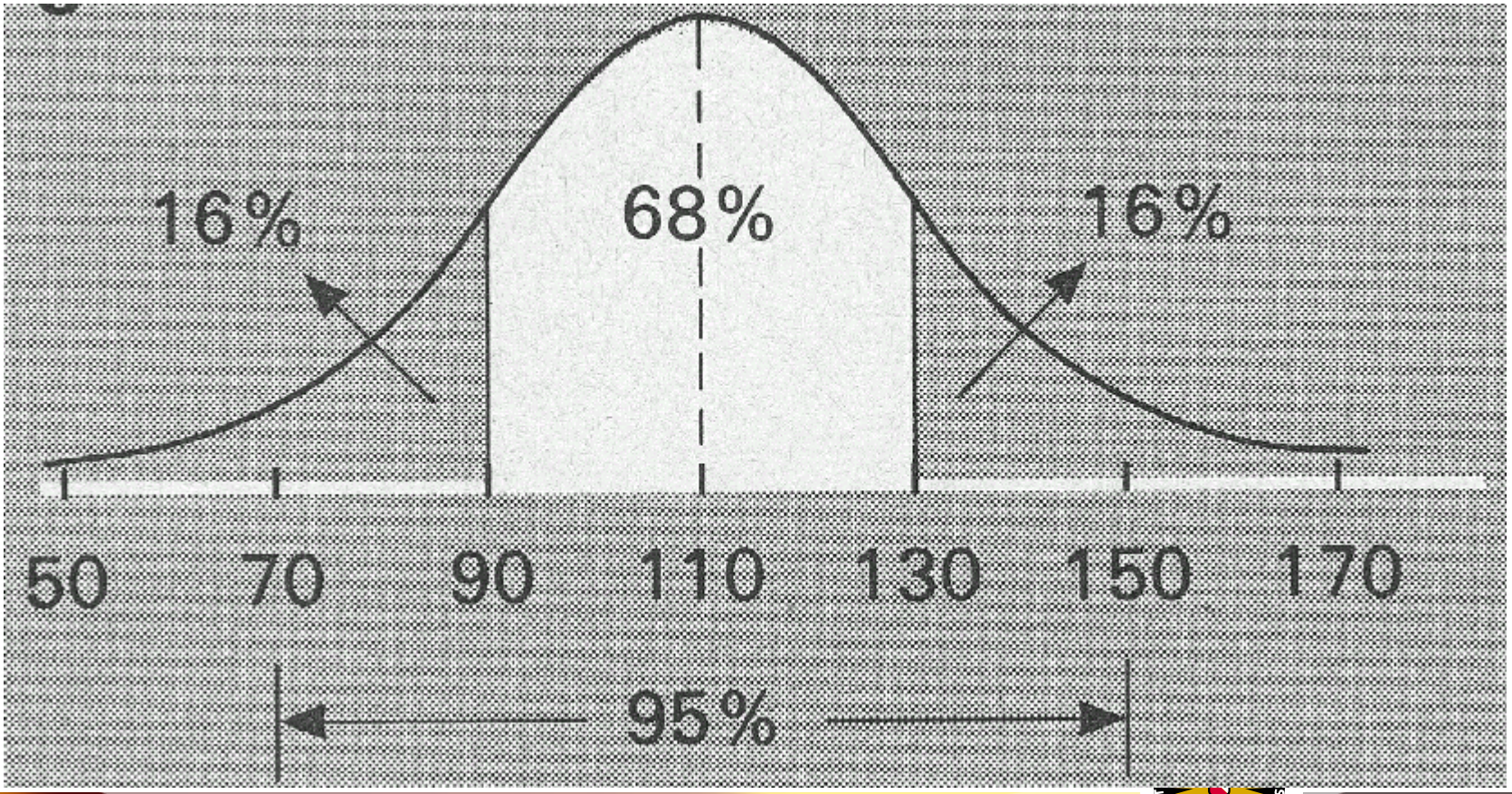
Limitations of statistical uncertainty

Reliability intervals in case of normal distributions

$\pm \sigma = 68\ \%$

$\pm 2\sigma = 95\ \%$

$\pm 3\sigma = 99.7\ \%$



Limitations of statistical uncertainty II

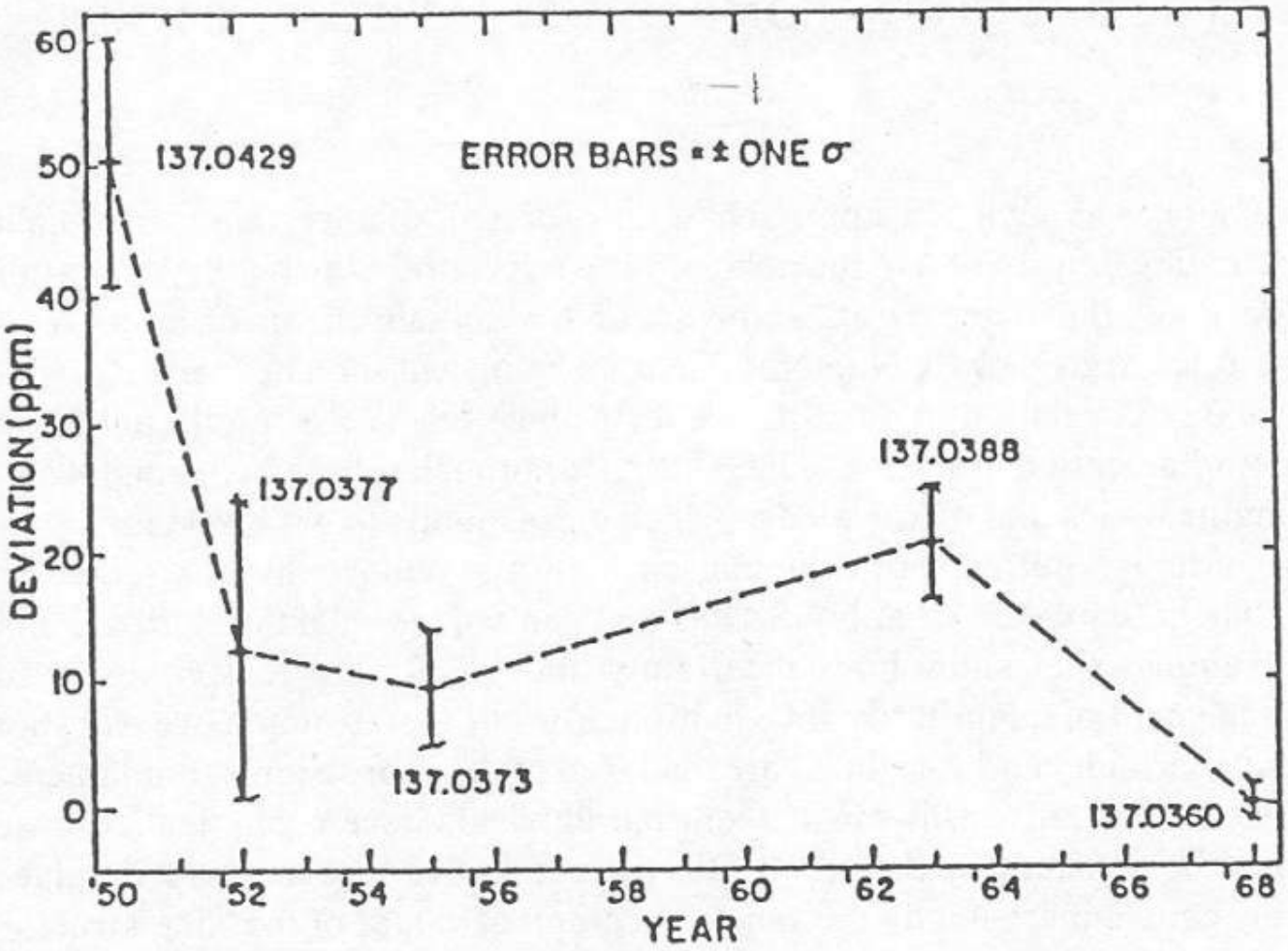
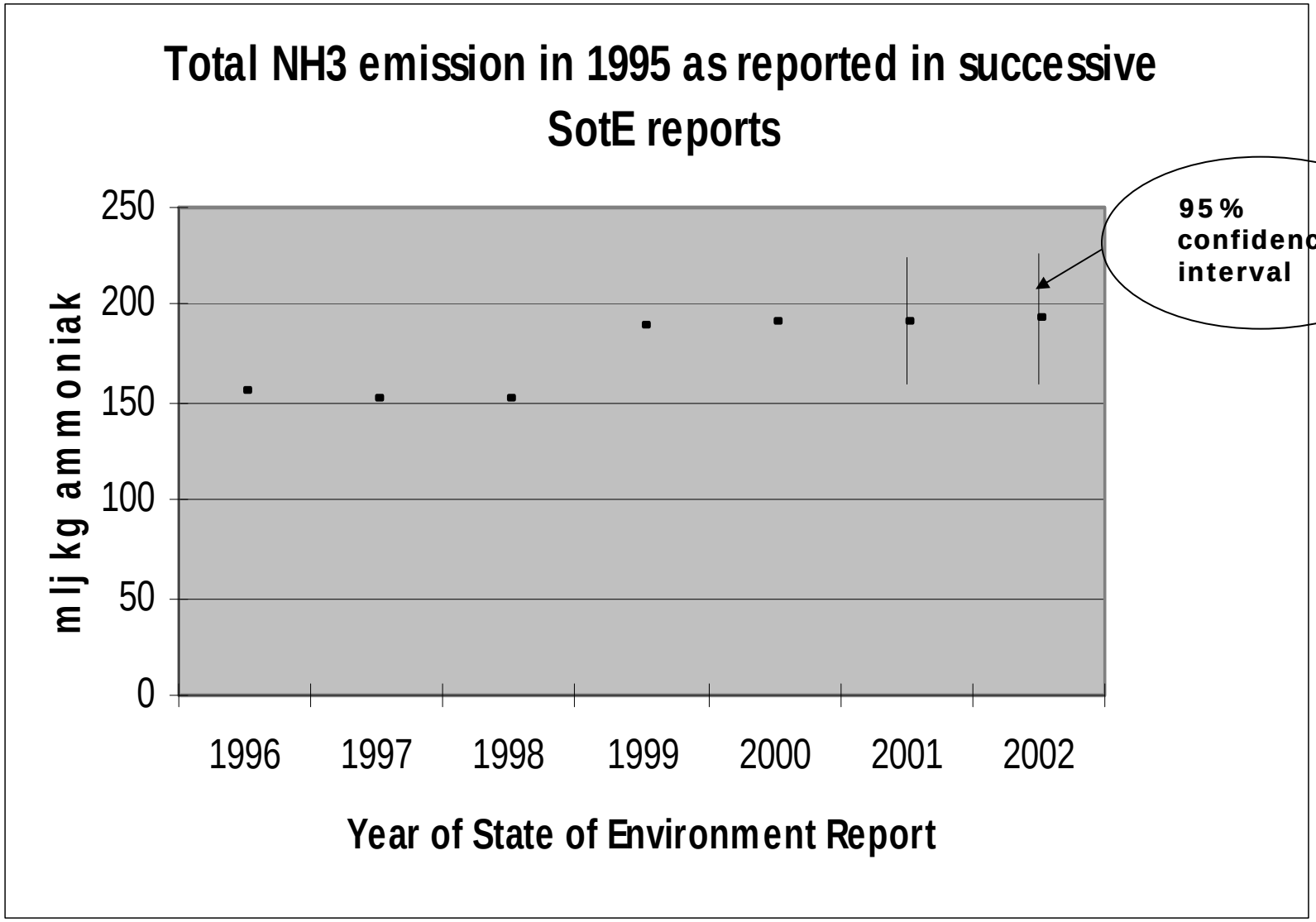


Fig. 1. Successive recommended values of the fine-structure constand α^{-1} (B. N. Taylor *et al.*, 1969, 7)

Handbook of Chemistry and Physics has only 3 qualifiers of information:
- Numeral
- Unit
- Spread

It might be helpful to provide more information on uncertainty.

Limitations of statistical uncertainty III



NUSAP
Qualified Quantities

- Numeral
- Unit
- Spread
- Assessment
- Pedigree

(Funtowicz and Ravetz, 1990)

NUSAP: Pedigree

Evaluates the strength of the number by looking at:

- Background history by which the number was produced
- Underpinning and scientific status of the number

Example Pedigree matrix parameter strength

Code	Proxy	Empirical	Theoretical basis	Method	Validation
4	Exact measure	Large sample direct mmts	Well established theory	Best available practice	Compared with indep. mmts of same variable
3	Good fit or measure	Small sample direct mmts	Accepted theory partial in nature	Reliable method commonly accepted	Compared with indep. mmts of closely related variable
2	Well correlated	Modeled/derived data	Partial theory limited consensus on reliability	Acceptable method limited consensus on reliability	Compared with mmts not independent
1	Weak correlation	Educated guesses / rule of thumb est	Preliminary theory	Preliminary methods unknown reliability	Weak / indirect validation
0	Not clearly related	Crude speculation	Crude speculation	No discernible rigour	No validation

NUSAP applied to TIMER energy model: Expert Elicitation Workshop

- Focussed on 40 key uncertain parameters grouped in 18 clusters
- 18 experts (in 3 parallel groups of 6) discussed parameters, one by one, using information & scoring cards
- ***Individual*** expert judgements, informed by group discussion

Structural change / Growth elasticity

Sub module: dem

Definition: These parameters describe the structural change curve. When an economy grows it is assumed to go through successive stages of development. In TIMER, based on historic analysis, that this is also reflected in terms of the demand for energy services in different energy end-use sectors. For instance, in early stages of development the industry sector is dominated by light industry; in a next stage heavy industry dominates and finally industry with high-value added. Consequently the energy intensity of a economy is assumed to go through a maximum with increasing GDP per capita (at PPP). In TIMER, the structural change formulation can be characterised by two important parameters:

Position maximum: Position of the maximum in the GDP per capita (at PPP) vs energy intensity curve

Saturation level: This parameter represents a theoretical minumum in energy intensity, associated with a saturation in energy demand per capita as a function of GDP per capita (at PPP). Note that this saturation point is assumed to be strongly scenario dependent. In a A-storyline the saturation is not met before 2100, in a B storyline it is.

Background Information:

	B1 range:	**Range over which sensitivity was tested:**
Position maximum:	1189.22, 1.0E+05 1995US$	100.00, 1.0E+05
Saturation level:	0, 3.5E-03 GJ/1995 US$	0, B1 value +50%

Rank in Morris Sensitivity Analysis (maximums are listed from this group of parameters)

Grouped by	Rank	μ(μ)	σ(μ(μ))	μ(σ)
Type:	1	873%	587%	2008%
Module	1	423%	278%	1051%

Dimension	17 Regions	5 Sectors	heat/electricity	5 energy carriers	Other
Variable	x	x	x		

Likely Uncertainty Range: *Maximum:* ± _____ % *Saturation:* ± _____ %

Characterization of variable

	Negligible	0	1	2	3	4	High	Elaboration/justification
Value-ladenness								

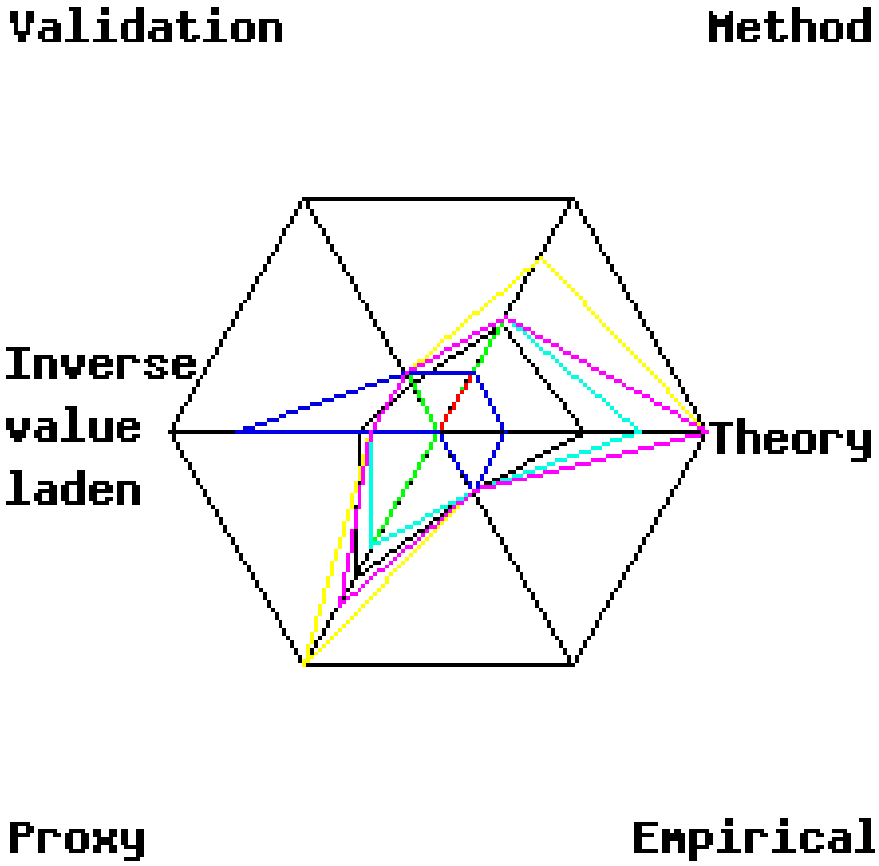
Pedigree

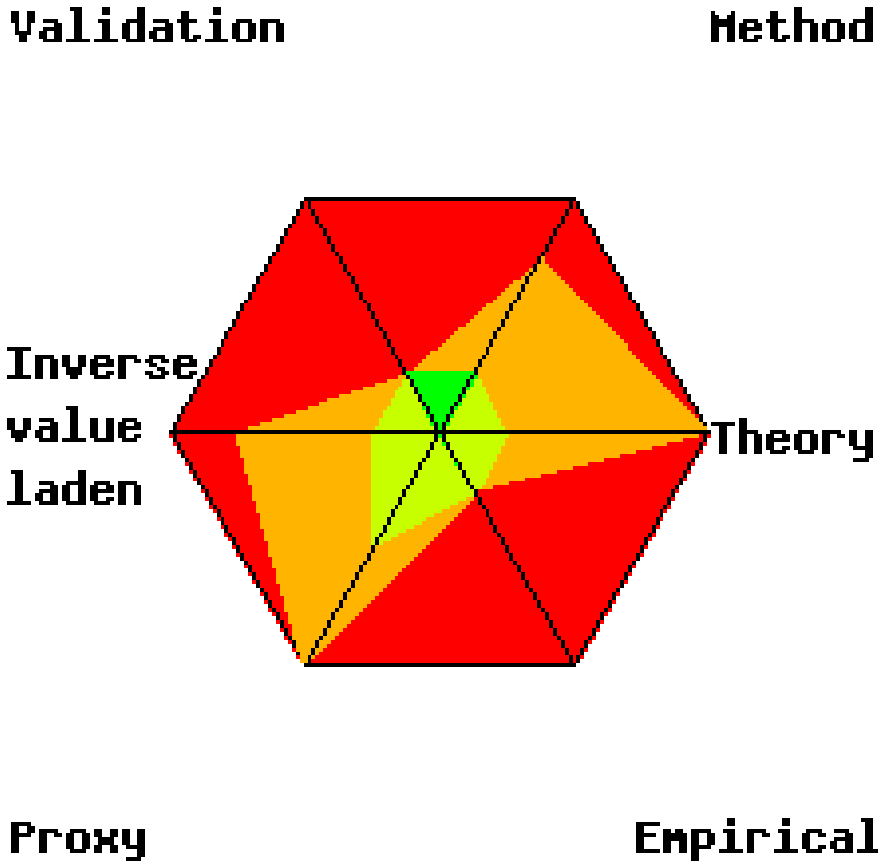
		0	1	2	3	4		Elaboration/justification
Proxy	**Not Related**						**Exact Measure**	
Empirical basis	**Weak**						**Strong**	
Theoretical understanding	**Weak**						**Strong**	
Methodological rigour	**Low**						**High**	
Validation	**No**						**Complete**	

Instructions

- Do the Pedigree assessment as an **individual** expert judgement, we do not want a group judgement
- Main function of group discussion is clarification of concepts
- Group works on one card at a time
- If you feel you cannot judge the pedigree scores for a given parameter, leave it blank

Example result *gas depletion multiplier*

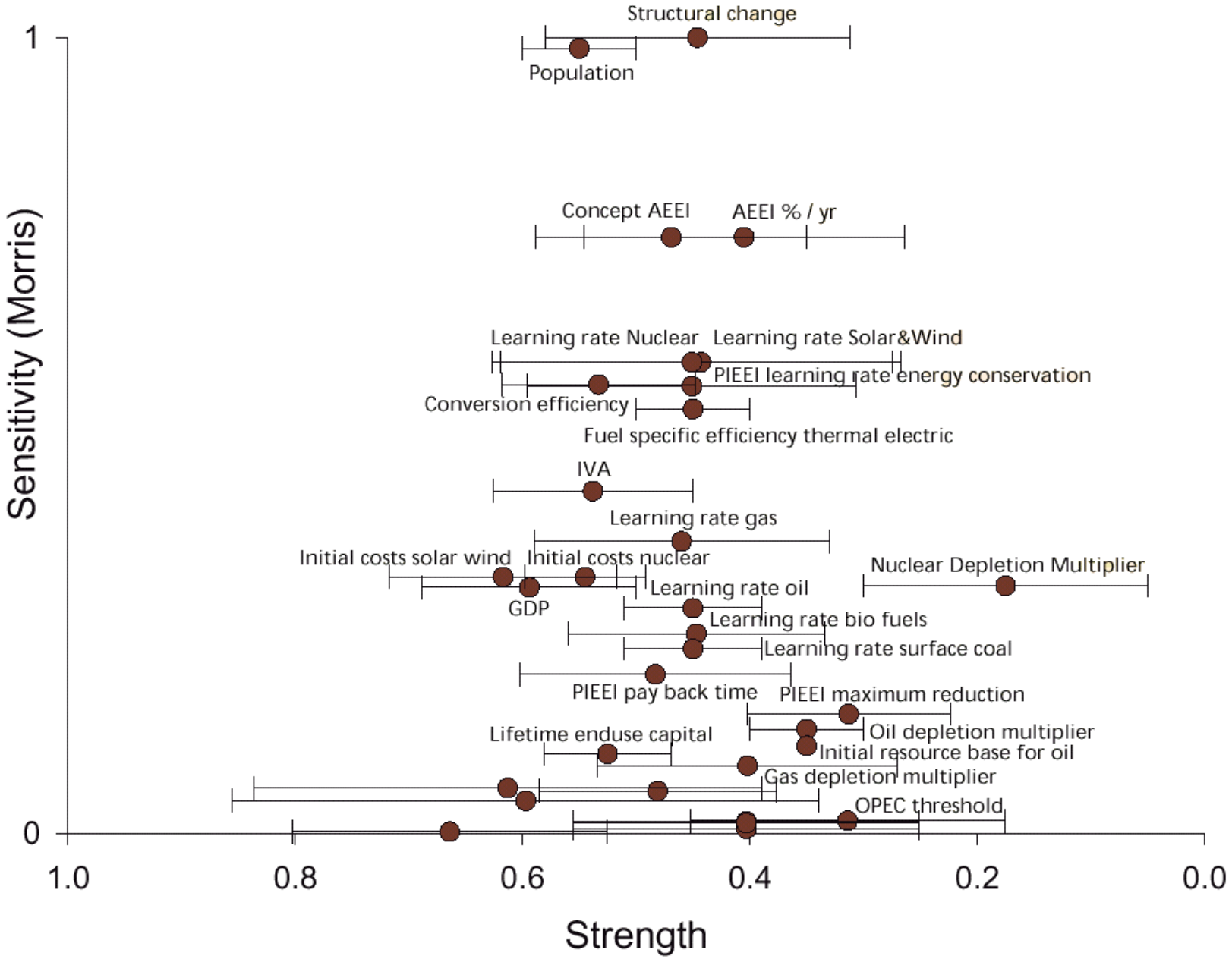




Radar diagram:
Each coloured line represents scores given by one expert

Same data represented as kite diagram:
Green = min. scores, Amber= max scores,
Light green = min. scores if outliers omitted
(Traffic light analogy)

Diagnostic Diagram



Pedigree matrix for evaluating the tenability of a conceptual model

Score	Supporting empirical evidence		Theoretical understanding	Representa-tion of understood underlying mechanisms	Plausibility	Colleague consensus
	Proxy	Quality and quantity				
4	Exact measures of the modelled quantities	Controlled experiments and large sample direct measurements	Well established theory	Model equations reflect high mechanistic process detail	Highly plausible	All but cranks
3	Good fits or measures of the modelled quantities	Historical/field data uncontrolled experiments small sample direct measurements	Accepted theory with partial nature (in view of the phenomenon it describes)	Model equations reflect acceptable mechanistic process detail	Reasonably plausible	All but rebels
2	Well correlated but not measuring the same thing	Modelled/derived data Indirect measurements	Accepted theory with partial nature and limited consensus on reliability	Aggregated parameterized meta model	Somewhat plausible	Competing schools
1	Weak correlation but commonalities in measure	Educated guesses indirect approx. rule of thumb estimate	Preliminary theory	Grey box model	Not very plausible	Embrionic field
0	Not correlated and not clearly related	Crude speculation	Crude speculation	Black box model	Not at all plausable	No opinion

Model Quality Assessment

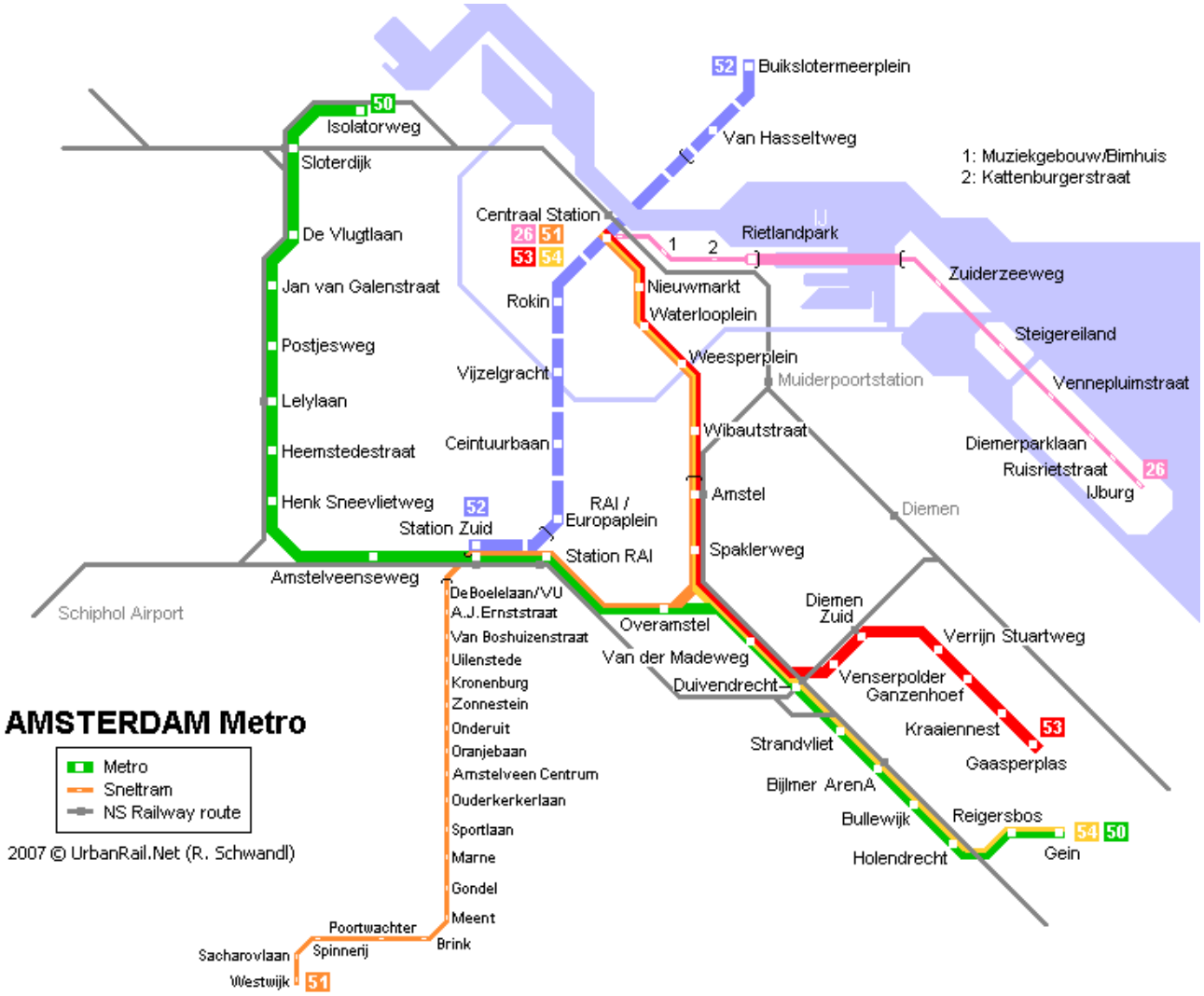
- Models are **tools**, not truths
- **A model is not *good* or *bad* but** there are **'better' and 'worse' forms of modelling practice**
- Models are 'more' or 'less' useful when applied to a particular problem.

Model Quality Assessment can provide:

- insurance against pitfalls in process
- insurance against irrelevance in application

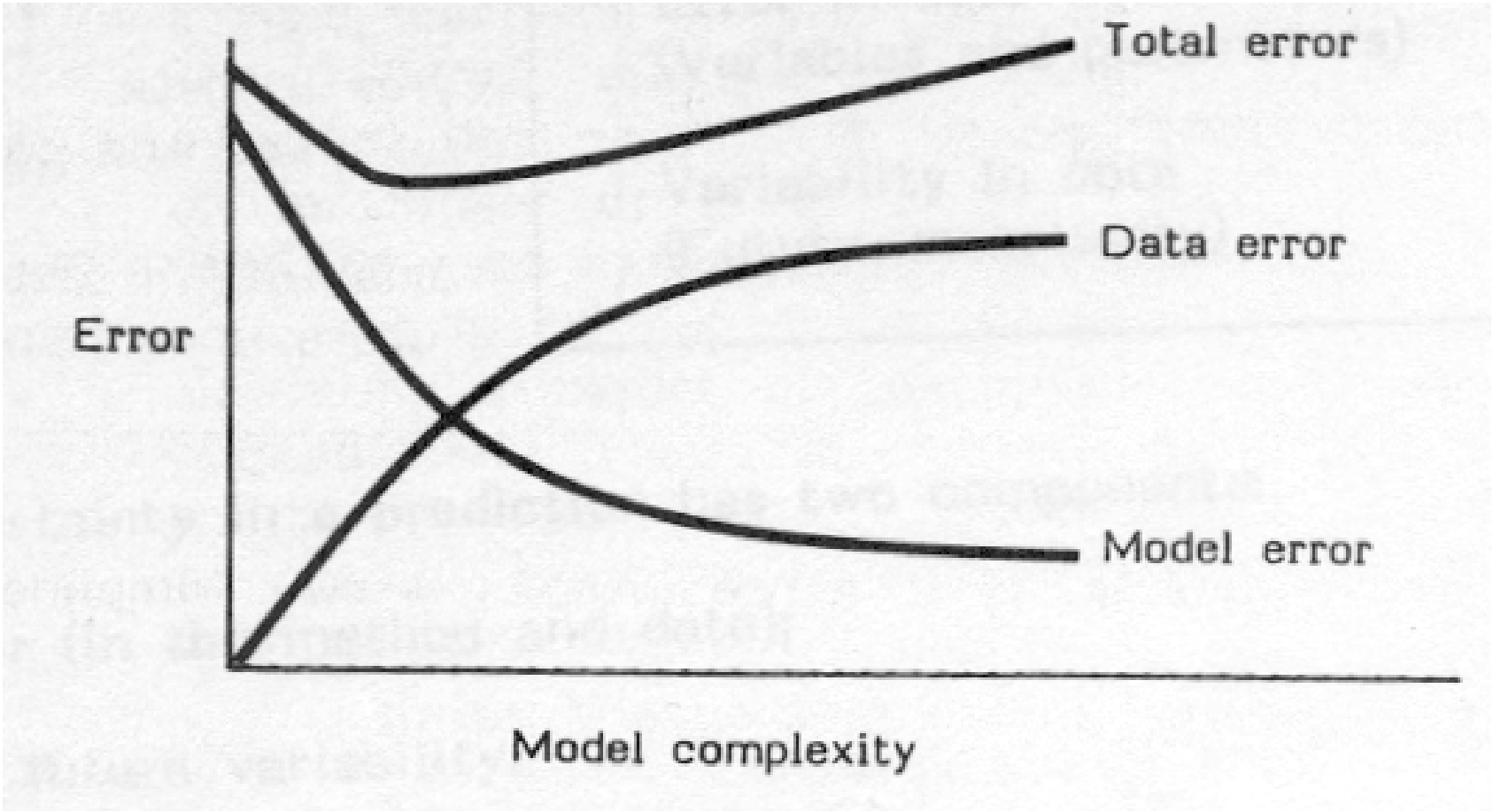
refs: www.mnp.nl/guidance
Risbey, J., J. van der Sluijs, et al. (2005): Application of a Checklist for Quality Assistance in Environmental Modelling to an Energy Model. *Environmental Modeling & Assessment* **10** (1), 63-79.

A model can have higher fitness for function (=quality) by being a less true representation of reality!

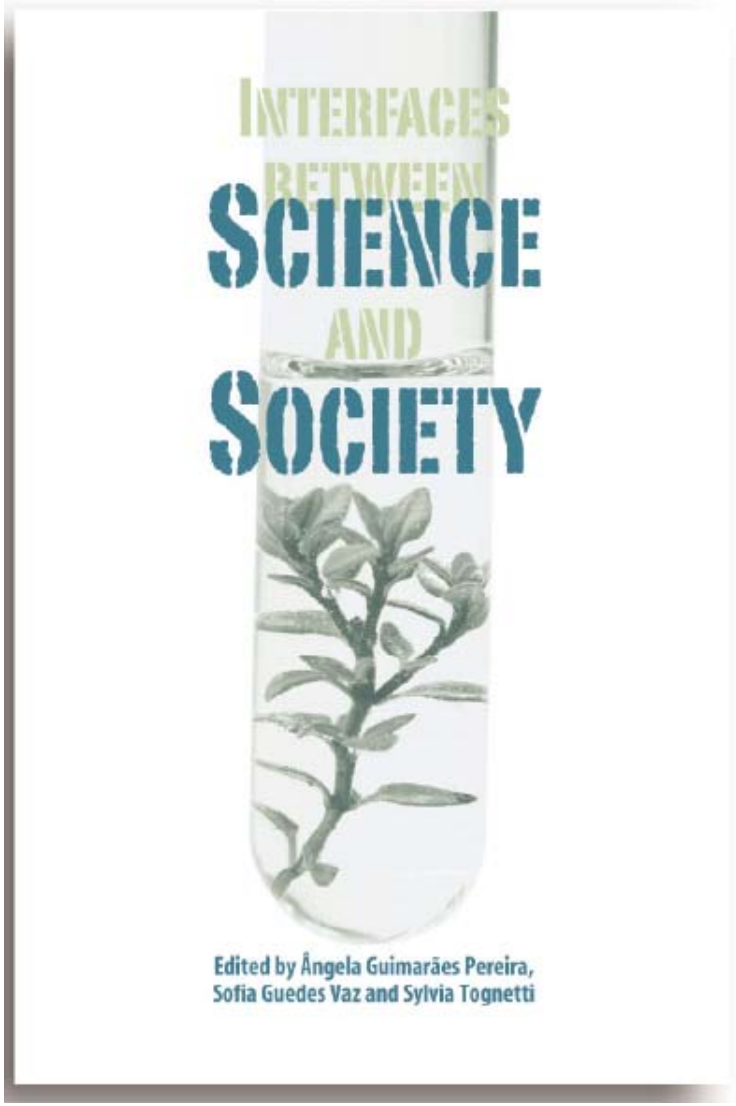


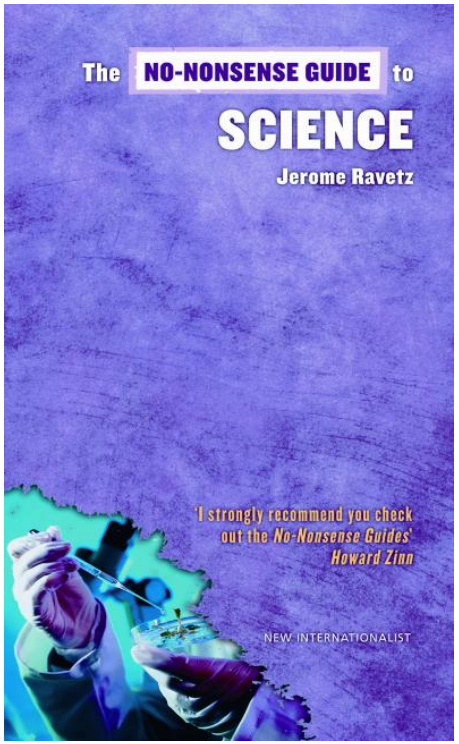
models as "stylized facts"

Uncertainty and model complexity



Books





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