Understanding the modelling process and model use

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10th International Conference on Sensitivity Analysis of Model Output (SAMO)

University of Reading

Contents

- Why do we model?
- Limits of scientific knowledge and uncertainty in modelling
- Tools for modelling and knowledge quality appraisal
- Practical examples
- Lesson learned and ways forward

1. Why do we model?

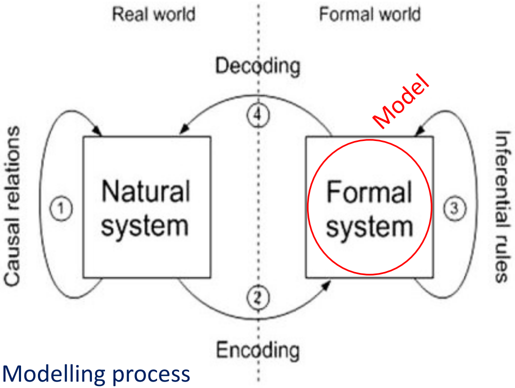
- Illustration (of a system, phenomenon, etc.)
- Description (e.g. in terms of accounting)
- Theoretical exposition (models as mediators)
- Explanation (understand/propose causalities)
- Prediction (understand future trends/patterns from past trends/patterns)

Edmonds 2019, *Different Modelling Purposes*

1. Why do we model?

- Other possible functions/taxonomies include guide data collection, discover new questions, etc.
- Do not take for granted that a model developed for a given purpose can be automatically used or adjusted for a different one.

Epstein 2008, *Why Model?*



Modelling process

Rosen 1991, *Life itself*

2. What limits to scientific knowledge

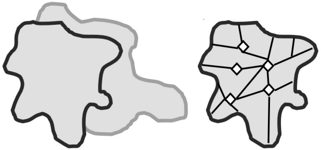
Three interwoven forms of uncertainty (other taxonomies possible)

- **Errors:** Limits of exactness of measures
- **Randomness:** Limits of causality and determinism as observed in the natural world
- **Statistics:** Limits of correspondence between descriptive categories and the reality they refer to.

Funtowicz and Ravetz 1990, *Uncertainty and Quality in Science for Policy*

Three dimensions of uncertainty

- **Location:** Context vs. Model Structure
- **Level:** Determinism -> Ignorance: Statistical Uncertainty -> Scenario U. -> Recognised Ignorance -> Total Ignorance (Unknown unknowns)
- **Nature:** Epistemic vs. Stochastic (reducible, imperfect knowledge, only partially quantifiable vs. irreducible, inherent variability, quantifiable)



Walker et al. 2003, *Defining uncertainty - A conceptual basis for uncertainty management in model-based decision support*

3.1 Tools: What kind of quantifications and models

Forms of quantifications (models, metrics, indicators) at the society-environmental-technology nexus, where new paradigms are requested because

- Facts are uncertain
- Stakes are high
- Decisions are urgent
- Values are contrasted

Funtowicz and Ravetz 1993, *Science for the Post-normal Age*

3.1 Tools: What kind of quantifications and models

Critical criteria to assess scientific inquiries in the policy context

Critical Role	Critical Mode: Input	Output	Process
Scientist	Resource and time constraints; available theory; institutional support; assumptions; quality of available data; state of the art.	Validation; sensitivity analyses; technical sophistication; degree of acceptance of conclusions; impact on policy debate; imitation; professional recognition.	Choice of methodology (e.g., estimation procedures); communication; implementation; promotion; degree of formalization of analytic activities within the organization.
Peer Group	Quality of data; model and/or theory used; adequacy of tools; problem formulation. Input variables well chosen? Measure of success specified in advance?	Purpose of the study. Are conclusions supported by evidence? Does model offend common sense? Robustness of conclusions; adequate coverage of issues.	Standards of scientific and professional practice; documentation; review of validation techniques; style; interdisciplinarity.
Program Manager or Sponsor	Cost; institutional support within user organization; quality of analytic team; type of financing (e.g., grant vs. contract).	Rate of use; type of use (general education, program evaluation, decisionmaking, etc.); contribution to methodology and state of the art; prestige. Can results be generalized, applied elsewhere?	Dissemination; collaboration with users. Has study been reviewed?
Policymaker	Quality of analysts; cost of study; technical tools used (hardware and software). Does problem formulation make sense?	Is output familiar and intelligible? Did study generate new ideas? Are policy indications conclusive? Are they consonant with accepted ethical standards?	Ease of use; documentation. Are analysts helping with implementation? Did they interact with agency personnel? With interest groups?
Public Interest Groups	Competence and intellectual integrity of analysts. Are value systems compatible? Problem formulation acceptable? Normative implications of technical choices (e.g., choices of data).	Nature of conclusions; equity. Is analysis used as rationalization or to postpone decision? All viewpoints taken into consideration? Value issues.	Participation; communication of data and other information; adherence to strict rules of procedure.

Clark and Majone 1985, *The Critical Appraisal of Scientific Inquiries with Policy Implications*

3.1 Tools: The seven-point sensitivity auditing *SAUD* checklist

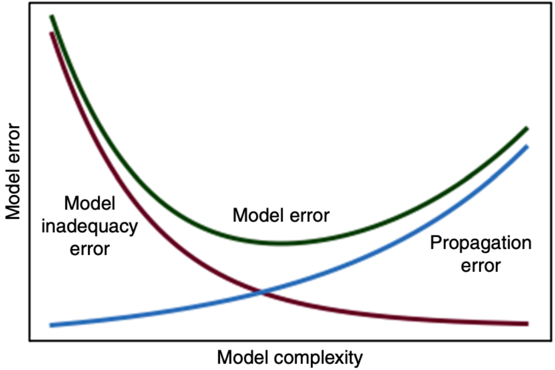
Extension beyond technical uncertainty and sensitivity analysis to quantifications (models, indicators, metrics) at the science-policy interface

- **Rhetorical use:** Are large models being used where simpler ones would suffice? Are model results and scope extrapolated beyond their intended range/settings of applicability?
- **Assumptions hunting:** What assumptions were made? Were these explicit or implicit?
- **Detect Garbage in Garbage out, GIGO:** Was the uncertainty in the input artificially constrained/bloated to boost the model's certainty/uncertainty? (E.g. to prevent regulation in a case of harmful products)
- **Anticipate criticism:** Find sensitive assumptions before they find you through robust UA and SA
- **Aim for transparency:** Avoid black-box models (e.g. PRIMES, EU energy policy)
- **Do the right sums:** Not just the sums right - does the model address the "right" problem, are multiple perspectives on the issue included?
- **Perform UA, SA:** Perform thorough and state-of-the-art UA and SA.

Saltelli and Funtowicz 2014, *When all models are wrong*

3.1 Tools: *SAUD* @ SAMO

- **Rhetorical use:** Are large models being used where simpler ones would suffice? Are model results and scope extrapolated beyond their intended range/settings of applicability?
  Session 4 Puy - *Sensitivity analysis as a tool to probe into the relation between model complexity and uncertainty*



3.2 SAUD, Manifesto for responsible modelling and Sociology of Quantification

- **Mind the assumptions:** Assumption hunting; Anticipate Criticism; Perform UA and SA
- **Mind the hubris:** Rhetorical use
- **Mind the framing:** Do the right sums
- **Mind the consequences:** Do the right sums
- **Mind the unknowns:** Detect GIGO

Session 2B Saltelli - *What can sensitivity analysis contribute to a sociology of quantification?*

Saltelli, Bammer, Bruno, Charters, Di Fiore, Didier, Espeland, Kay, Lo Piano, Mayo, Pielke, Portaluri, Porter, Puy, Rafols, Ravetz, Reinert, Sarewitz, Stark, Stirling, van der Sluijs, Vineis 2020, *Five ways to ensure that models serve society: a manifesto*
Lo Piano, Sheikholeslami, Puy and Saltelli, under cons. *Unpacking the modelling process via sensitivity auditing*

3.3 NUSAP

- The NUSAP scheme for the management and communication of uncertainty
- NUSAP (Numeral, Unit, Spread, Assessment and Pedigree)

Funtowicz and Ravetz 1990, *Uncertainty and Quality in Science for Policy*
van der Sluijs et al. 2005, *Combining Quantitative and Qualitative Measures of Uncertainty in Model-Based Environmental Assessment: The NUSAP System*

Estimating the uptake of radioactive isotopes from cow milk

- Radioactive decay constant for ^{137}Cs
- **Keyword**: ^{137}Cs, radioactive constant
- **Numeral** : 0.023
- **Unit** : $year^{-1}$
- **Spread** : -
- **Assessment**: high
- **Pedigree** : (4,4,4)

- Milk intake rates for individuals
- **Keyword**: Average milk consumption, total UK population
- **Numeral** : 150
- **Unit** : $l \cdot y^{-1}$
- **Spread** : ± 50
- **Assessment**: medium
- **Pedigree** : (2,2,2)

Funtowicz and Ravetz 1990, *Uncertainty and Quality in Science for Policy*

3.3 NUSAP - Research-based Pedigree

Theoretical structures

- Established Theory
- Theoretically-based model
- Conceptual model
- Statistical processing
- Definitions

Data-input

- Experimental data
- Historic/field data
- Calculated data
- Educated guesses
- Uneducated guesses

Peer acceptance

- Total
- High
- Medium
- Low
- None

Colleague consensus

- All but cranks
- All but rebels
- Competing schools
- Embryonic field
- No opinion

3.4 Relevant fields of application of SAUD to modelling and quantification

- Education (Programme for International Student Assessment) PISA test Araujo et al. 2017 *Do PISA data justify PISA-based education policy?*
- Nutrition and public health economic evaluations Lo Piano and Robinson 2019
- Ecological Footprint accounting scheme of sustainability Giampietro and Saltelli 2014 *Footprints to nowhere*
- Sociohydrology Lo Piano, Sheikholeslami, Puy and Saltelli, under cons. *Unpacking the modelling process via sensitivity auditing*

3.4 Relevant fields of application of NUSAP

- External cost estimation for nuclear energy Laes et al. 2011 *On the Contribution of External Cost Calculations to Energy System Governance: The Case of a Potential Large-Scale Nuclear Accident*
- Energy modelling support for UK policy Pye et al. 2018 *Assessing Qualitative and Quantitative Dimensions of Uncertainty in Energy Modelling for Policy Support in the United Kingdom*
- Negative emission technologies uptake in Integrated Assessment Models Vaughan and Gough 2016 *Expert Assessment Concludes Negative Emissions Scenarios May Not Deliver*

4 Case study: Life-cycle assessment

- What are the impacts linked to the provision of a good or service/production process/larger system (area/whole country, etc.)?
- Is product A better/worse (more/less impactful) than product B?
- International Organisation for Standardization (ISO) 14000 procedures to conduct LCA
- Product ecolabels

4 Case study: LCA

JOURNAL OF
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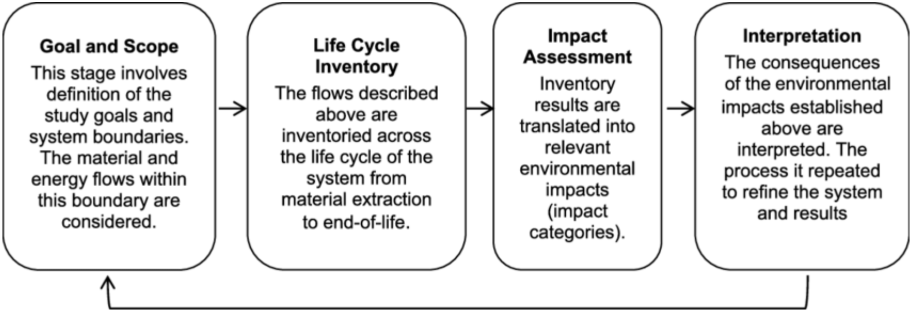
A critical perspective on uncertainty appraisal and sensitivity analysis in life cycle assessment

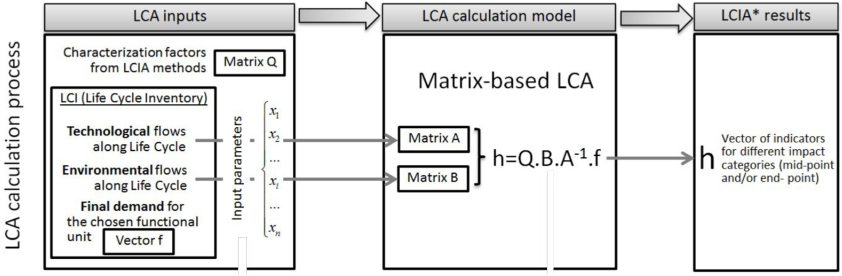
Samuele Lo Piano, Lorenzo Benini

First published: 10 February 2022 | https://doi.org/10.1111/jiec.13237

Editor Managing Review: Mark Huijbregts

4 Case study: LCA



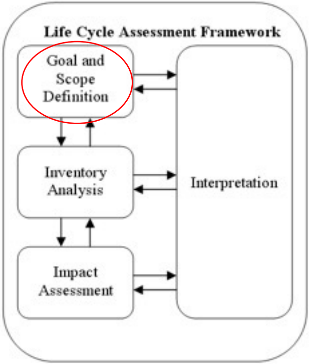


$$h = Q \cdot B \cdot A^{-1} \cdot f$$

- *h* impacts
- *Q* matrix of characterisation factors
- *B* environmental matrix
- *A* technology (or economic matrix)
- *f* final demand matrix

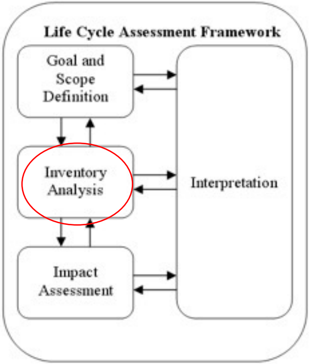
Wei et al. 2015, *How to Conduct a Proper Sensitivity Analysis in Life Cycle Assessment [. . .]*

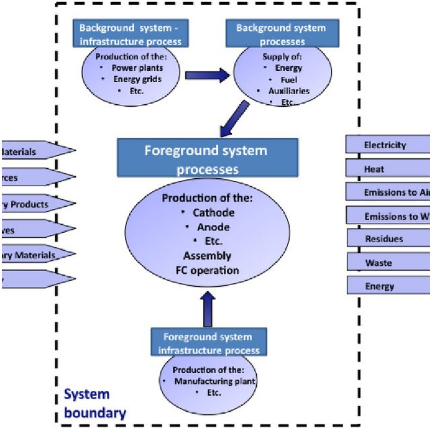
4.2 LCA - sources of uncertainty



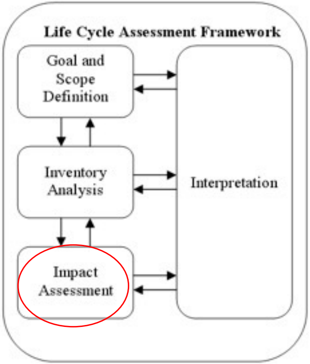
- System boundaries
- Allocation (economic, material, energy, etc.)
- Functional unit (per output, land, machine unit, etc.)

4.2 LCA - sources of uncertainty

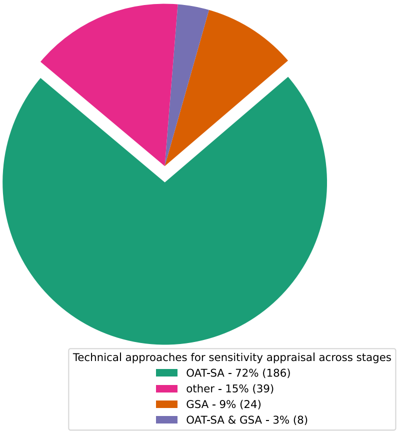




4.2 LCA - sources of uncertainty

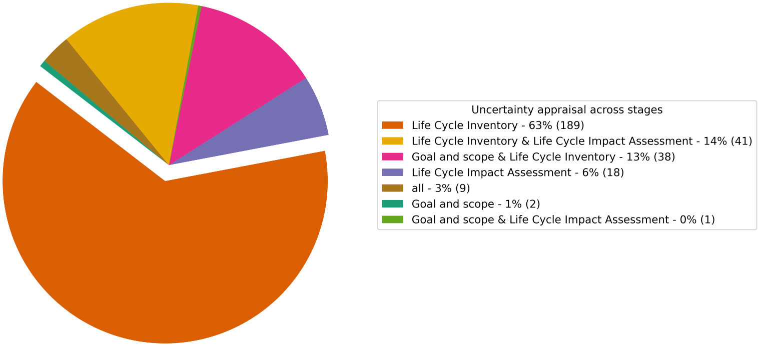


- Emission, characterisation factors, time horizon
- Mid- vs. end-point impact assessment (single environmental problem vs. end-of-chain impact, e.g. biodiversity), weight attributed to impact categories

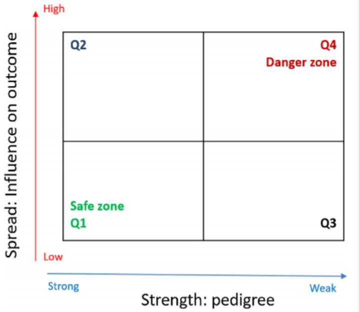


- Overall, uncertainty was somehow appraised and/or apportioned in only $1-2\%$ of the studies. Anticipate criticism
- On the apportioning of uncertainty, most of the studies were one-variable-at-a-time (OAT) Perform UA and SA

- Most of the studies focused only on the inventory stage, thus downplaying uncertainty Perform UA and SA

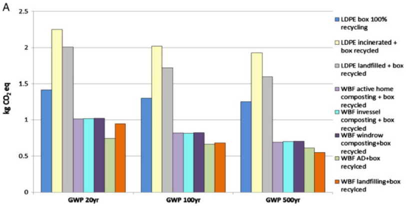


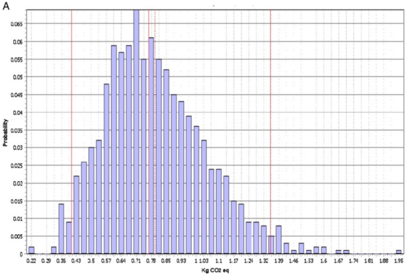
4.3 LCA - uncertainty appraisal, DOE



Mind the unknowns

- Lognormal distributions b/c already available from inventories, account for skewness, do not sample negative values (unlike normal dists.)
  Mattila et al. 2011, *Uncertainty and sensitivity in the carbon footprint of shopping bags* Detect GIGO
- Pedigree coefficients (i)reliability, ii) completeness; iii) temporal, iv) geographical and v) further technological correlation) used as multiplicative figures: weaker pedigree -> larger std Detect GIGO





- Independent UA and SA, different designs of experiment, or on different phases as uncorrelated. Perform UA and SA

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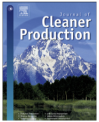
4.3 LCA - Do the right sum!

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro



The carbon footprint of breastmilk substitutes in comparison with breastfeeding

Journal of Environmental Accounting and Management

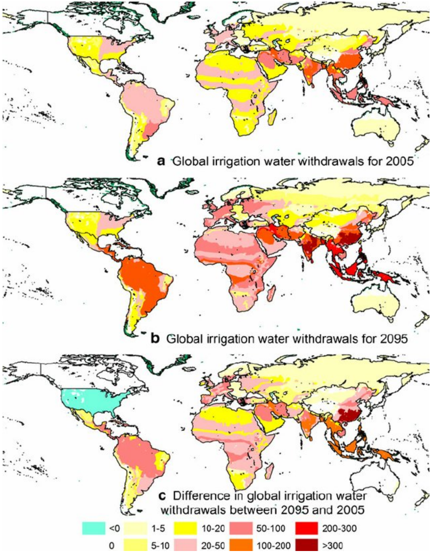
Journal homepage: https://lhscientificpublishing.com/Journals/JEAM-Default.aspx

Life Cycle GHG Emission Comparison of Infant Nursing Using Breast Milk Versus Formula

4.4 LCA - final points

- State-of-the-art practices, including GSA, largely overlooked
- These findings do not necessarily represent the practices of the entire community of LCA practitioners

5 Estimates of global irrigation water withdrawals



- Policy making at the agriculture-water interface (relevant *i.a.* for various Sustainable Development Goals: Clean Water and Sanitation, Zero Hunger, Life on Land)
- Performed through global hydrological models

Chaturvedi et al. 2013, *Climate mitigation policy implications for global irrigation water demand*

5 Estimates of global irrigation water withdrawals

$$y = \frac{I_a(ET_c - P)}{E_p}$$

- y: irrigation water withdrawals
- I_a: extension of irrigation area
- ET_c: crops evotranspiration
- P: precipitation
- E_p: irrigation efficiency

Puy, Sheikholeslami, Gupta, Hall, Lankford, Lo Piano, Meier, Pappenberg, Porporato, Vico, Saltelli, under cons. *The delusive accuracy of global irrigation water withdrawal estimates*

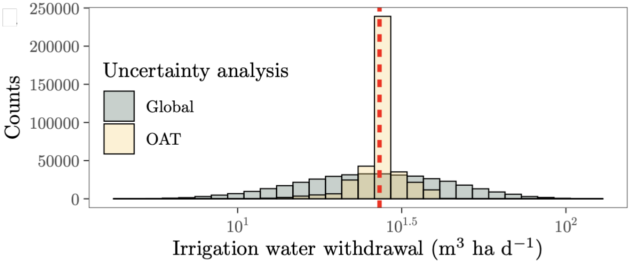
5 Estimates of global irrigation water withdrawals Mind the assumptions

$$y = \frac{I_a(ET_c - P)}{E_p}$$

- However, uncertainty largely overlooked in terms of canopy interception of precipitation, surface losses and percolation, change in soil water storage (dependent on the time frame)
- $y = \frac{I_a(ET_c - P)}{E_p}$ Neglect of several maps available for irrigation, up to four orders of magnitude at country level Puy, Lo Piano and Saltelli, 2020
  Current models underestimate future irrigated areas
- $y = \frac{I_a(ET_c - P)}{E_p}$ Neglect of several equations available for evotranspiration

  $y = \frac{I_a(ET_c - P)}{E_p}$ Neglect of several possible figures for efficiency, questionable distinction between small and large irrigated areas.

5 Estimates of global irrigation water withdrawals Mind the assumptions



Specific grid cell in the Uvalde County, Texas (x = -99.7084, y = 29.4583)

- $y = \frac{I_a(ET_c - P)}{E_p}$
- Piece-wise vs. joint UA (Monte Carlo)

5 Estimates of global irrigation water withdrawals

- Pushing on model complexity may lead to even less accuracy, with more rather than less uncertainty (e.g., uncertainty cascade) Mind the hubris
- Ethical issue -> pushing towards more resolution may expose informal irrigators that survive by going off the radar Mind the consequences
- Questionable assumptions on efficiency (e.g. lack of maintenance, irrigators may have different goals than maximising efficiencies) Mind the framing

6 Conclusions

- UA and SA can help us to reveal blind spots in quantifications at the science-policy interface
- Enhancement on the epistemic level (sensitivity auditing, NUSAP) increase the reflexivity of sensitivity analysis
- Mainstreaming their use could largely benefit the decision making process (ref. *The Future of Sensitivity Analysis*)

Thank you for your kind attention, SAMO Community!

I am looking forward to your questions.

Let's stay in touch: s.lopiano@reading.ac.uk

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