Mainstreaming Sensitivity Analysis and Uncertainty Auditing

UC Berkeley (US), Universities of Bergen and Trondheim (NO)

Fall 2017 - Fall 2018

Principal Investigators

Philip B. Stark, Professor of Statistics and Associate Dean of Mathematical and Physical Sciences, UC Berkeley

Andrea Saltelli, Adjunct Professor, Centre for the Study of Science and Humanities (SVT), U. of Bergen

Jeroen van der Sluijs, Professor, Centre for the Study of Science and Humanities (SVT), U. of Bergen

OTHER PARTICIPANTS

Leif Rune Hellevik, Professor, Department of Structural Engineering, U. of Trondheim

PROJECT ABSTRACT

Decisions with profound societal consequences often rely on approximate numerical models of physical systems, calibrated to noisy, incomplete data. Sensitivity Analysis (SA) studies the sensitivity of such mathematical models to changes in the assumptions. It subsumes model validation and verification, Uncertainty Quantification, and also qualitative and philosophical issues. However, the discipline is underdeveloped and underused. We will consolidate and mainstream SA by identifying and developing best practices; developing open software, case studies, and other resources illustrating and implementing best practices; and developing graduate course modules to disseminate the knowledge, skills, and tools. We will leverage a previous Peder Sather Grant: Workshop On Uncertainty Quantification And Sensitivity Analysis For Cardiovascular Modeling. We will create a Berkeley-Bergen-Trondheim SA handbook, including reproducible/reusable/extensible software embodied in a python package and annotated examples in Jupyter notebooks. In applications with important societal consequences, e.g., policy planning or appraisal, SA should be augmented in a post-normal science style using methodologies such as NUSAP (a notational system for systematic appraisal and communication of quantitative and qualitative dimensions of uncertainty, Van der Sluijs et al., 2005) and sensitivity auditing. The case studies will show how these methodologies may lead analysts to be more circumspect, reducing irresponsible quantification.

OVERVIEW: PURPOSE AND OBJECTIVES OF THE PROJECT AND/OR RESEARCH QUESTION

The proposed research is at the intersection of applied statistics, public policy, science and technology studies, and philosophy of science. We will develop statistical methods and open software to understand the behavior of mathematical models (uncertainty quantification and sensitivity analysis), coupled with best practices to ensure the quality of evidence used for policy, such as NUSAP (https://en.wikipedia.org/wiki/NUSAP) and sensitivity auditing (https://en.wikipedia.org/wiki/Sensitivity_auditing), and pedagogical materials to promulgate these methods. Sensitivity analysis provides a unifying thread linking the various elements of the proposal.

Many spectacular scientific advances—from the detection of gravitational waves and the Higgs boson to landing a probe on a comet flying past the Sun—require the smooth operation and correctness of a myriad of mathematical and computational models and associated software. The best-known failures in this class of undertakings were caused by faulty software: errors in the shape of the Hubble Space Telescope mirror (pre-1990), the explosion of Arianne 5 in 1996, the 1999 loss of the Mars Climate Orbiter, and the botched Martian landing of the Schiaparelli probe in 2016. A known secret of sensitivity analysis is that it always leads to discovering more bugs (an instance jokingly known among computer nerds as 'Lubarsky's Law of Cybernetic Entomology'). The kind of breakthrough made possible by a diligent sensitivity analysis is not a kind reported in the media: the rocket's engines worked as planned, the flight assistant model gave the right message to the pilot, or the accident or disaster did not happen. The situation is similar when mathematical and computational models are used for policy simulation or assessment. An expenditure program based on a cost-benefit analysis that left most of its assumptions untested may easily cost the taxpayers decimals of GDP points and lost opportunities, providing nothing useful in return.

Uncertainty has many sources, not merely engineering and technical issues. Richard Feynman discovered while investigating the Challenger disaster that, while the low temperature and the properties of the O-rings could explain the material cause of the accident, its final causes were institutional, in the socio-political organization of NASA (https://www.youtube.com/watch?v=4kpDg7MjHps) and the drive of its management to go beyond what the engineers recommended. By coupling more conventional sensitivity analysis (concerned, e.g., with O-rings an analogous sources of uncertainty) with an extended sensitivity analysis (concerned, e.g., with the motivation and stakes of the actors), our proposed project moves the frontier of analysis forward, and avoids the focusing too much on simulations that seek to assess technical uncertainty but neglect other sources of uncertainty that are often much larger.

There are many unresolved questions in the emergent discipline of SA. Fleshing out SA requires joint analysis, testing, inter-comparisons, and collaboration and deliberation among practitioners. For example, what it means to say that factor A is more 'important' than factor B needs a careful specification. One has to define 'importance' before the analysis in the context of the application, or many different measures of importance may be thrown at the problem to get different ordering of the relative importance of input factors. This correspondence between task and measures of importance is rarely examined in the literature.

Related questions include how to select an SA method appropriate to an application or setting, how to choose a sampling scheme for screening factors, which meta-modeling (emulation) strategy is most effective in a given problem, how to check the accuracy of meta-models, and so on. These questions emerge every time practitioners meet, and the lack of a concentrated research effort hampers their systematic resolution.

The relatively low cost of research on SA and the importance of the potential benefits are clear. Avoiding even one of the accidents just mentioned would give benefits order of magnitude larger than the cost of this proposed research.

At the same time, teaching students that uncertainty is not merely technical but has important social and epistemological dimensions may help induce a more reflexive attitude and to prepare young scientists to make responsible use of quantification.

BACKGROUND/CONTEXT/OVERVIEW OF CURRENT RESEARCH

Practitioners of SA are scattered across various disciplines in science and engineering. Moreover, few researchers are engaged in teaching the subject. Given the ubiquity of statistical and mathematical models at the heart of science (both natural and social) and technology, some progress in refining and mainstreaming sensitivity analysis best practices on the two sides of the ocean appears promising, especially if it develops best practices and embodies them in software in the form of "executable documents" that can illustrate and replicate analyses, including a narrative explaining the considerations, thought processes, and choices involved, and how best to communicate the results. This will improve the usability and practice of SA in academic, industrial, and commercial applications and in impact assessment for policy appraisal.

SA forces modellers to adopt stricter standards of modelling practice and can show that model predictions are not robust. These are strengths of SA for responsible quantification, but may not be perceived as such by practitioners who care more about getting "results" than about the reliability of those results. A serious obstacle is that SA is not recognized as a discipline. The proposed collaboration addresses this by demonstrating how SA can be taught in a deep and systematic way to practicing scientists and graduate students, and practical examples will be used from ongoing projects such as "Workshop On Uncertainty Quantification And Sensitivity Analysis For Cardiovascular Modeling" and a research grant funded by the Research Council of

Norway: Scaling and Uncertainty Modelling in multiphase production. At the same time—another element of originality of the project—sensitivity analysis is presented in the context of its application to messy, controversial issues involving the use of models at the science–policy interface, where the style of argumentation can be confrontational. In this respect, sensitivity auditing, which extends SA to investigate the power relations and motivations underpinning the context of a given modelling effort, helps ensure that analyses do not remain abstract.

Recent reviews of sensitivity analysis include Norton (2015), and Wei et al. (2015). Reliability Engineering and System Safety (2006, 2012, 2015), and the Journal of Statistical Computation and Simulation (2015) have devoted special issues to SA. Several textbooks on SA are also available; they are reviewed in e.g. Norton (2015).

Sensitivity analysis is acknowledged to be useful in model development and application. Its use in regulatory settings (e.g., in impact assessment studies) is prescribed in guidelines both in Europe and the United States (European Commission, 2015, p. 390-393; Office for the Management and Budget, 2006, p. 17-18; Environmental Protection Agency, 2009, p.26).

Sensitivity analysis is not practiced as often as it should be and, when it is used, it generally is not practiced well (Ferretti et al., 2016). One impediment is that it is not part of the STEM curriculum. Even talented practitioners are unable–for lack of a critical mass–to bring these shortcomings to the attention of a wider scientific public. For example, the only SA paper published in a highly ranked generalist scientific journal is a 1989 paper in *Science* by Herschel Rabitz.

In the US at present, SA is under the umbrella of 'Verification, Validation and Uncertainty Quantification' (VVUQ), for which there is a journal of the American Society of Mechanical Engineers. There is also a Journal on Uncertainty Quantification under the auspices of the Society for Industrial and Applied Mathematics (SIAM) jointly with the American Statistical Association (ASA) https://juq.siam.org/cgi-bin/main.plex. China is home to an explosion of research on sensitivity analysis in recent years.

NUSAP is a notational system to manage and communicate uncertainty in science for policy, based on five categories for characterizing any quantitative statement: Numeral, Unit, Spread, Assessment, and Pedigree. This taxonomy structures the systematic appraisal and communication of the various dimensions of uncertainty. It provides a heuristic for good practice in addressing uncertainty in quantitative information and model-based inference. NUSAP extends statistical approaches to uncertainty with methodological and epistemological dimensions by adding expert judgement of reliability (Assessment) and systematic multi-criteria evaluation of the underpinning of numbers (Pedigree). Examples of pedigree criteria are empirical basis, methodological rigor, theoretical understanding, degree of validation, and peer acceptance.

NUSAP provides a means to synthesize and integrate findings on each of these dimensions, combining formal Monte Carlo and mathematical sensitivity analysis techniques with systematic qualitative uncertainty assessment. NUSAP enables providers and users of numerical information to be clear and transparent about its various uncertainties. This promotes critical

reflection on the strengths and weaknesses of the underlying knowledge base by users of all sorts (e.g., experts, lay public) and thereby supports an extended peer review process. It aims to provide those who produce, use and are affected by policy-relevant knowledge with a set of diagnostic tools for a critical self-awareness of their engagement with that knowledge (Van der Sluijs et al, 2008).

This project will build on NUSAP's potential to systematise the appraisal and consideration of uncertainty at the science-governance interface. Further tailoring and standardisation of pedigree matrices and procedures for the elicitation of pedigree scores are desirable, but the main challenge is in dissemination. Successful pilots with inclusion of NUSAP in MSc and PhD teaching curricula at the universities of Utrecht, Bergen, and Versailles Saint-Quentin-en-Yvelines can be scaled up. Resources for NUSAP can be found on a dedicated web site www.nusap.net and in (Van der Sluijs, 2017).

Sensitivity auditing is recommended by the European Commission guidelines for impact assessment (European Commission, 2015, p. 392-393, see http://ec.europa.eu/smart-regulation/guidelines/docs/br_toolbox_en.pdf).

Sensitivity auditing aims to extend sensitivity analysis to contexts where models are at play and their outcome feeds into the public discourse, be it in the context of a policy assessment (ex-ante or ex-post), or in the public arenas where policies are contested. Sensitivity auditing starts from the awareness that in an adversarial context not only the nature of the evidence, but also the degree of certainty and uncertainty associated to the evidence will be the subject of partisan interests. It includes a concept of quality assurance by an extended peer community—consisting not merely of persons with some form or other of institutional accreditation, but of all those with a desire and/or interest to participate in extended peer review processes for the resolution of a specific issue. The consideration and inclusion of actors' specific knowledge ultimately adds to the plausibility of model based inference. Sensitivity auditing's checklist includes:

1. Check for rhetorical use of mathematical modelling;
2. Adopt an 'assumption hunting' attitude;
3. Detect artificial inflation or deflation of the system uncertainties
4. Find sensitive assumptions before these find you;
5. Aim for transparency;
6. Do the right sums – be sure not to have neglected relevant framings of the issue at hand.
7. Focus the analysis on the key question answered by the model, exploring holistically the entire space of the assumptions.

Note that while some of these rules are a pointer to good versus bad practices (e.g. rule 7) some other call for a shift in the stance of the analysts (e.g. rule 1).

The present proposal will select (and in part create) and consolidate best practices in sensitivity analysis, sensitivity auditing and NUSAP with instructive examples—e.g. from cardiovascular modelling (see Eck et al., 2015)—a python package containing core functionality, and Jupyter notebooks (http://jupyter.org/ led by Fernando Perez at UC Berkeley and LBNL) illustrating best practices in several applications, as "executable documents" that show how to think through the

issues as well as how to compute or estimate relevant quantities. The software and notebooks will be open, transparent, extensible, and at a level that can be used to train practicing scientists and graduate students, to introduce this fundamental discipline into higher education curricula.

The four investigators (Stark, van der Sluijs, Hellevik and Saltelli) represent an ideal mix of competencies to blend this material into a coherent whole to try an experimental syllabus which spans from elements of calculus and statistics (for sensitivity analysis proper) via engineering application to elements of epistemology and history and philosophy of sciences which are needed to metabolize post-normal science, sensitivity auditing and NUSAP. Stark will teach a joint undergraduate/MA course in *Reproducible and Collaborative Statistical Data Science* (Statistics 159/259) in Fall 2017, which will be used as a testbed for the pedagogy. SA mates perfectly with the course themes of reproducibility and replicability, helping shed light on the spectrum of sources of uncertainty in putative scientific results, sources not routinely taken into account. The present proposal may be seen to respond to an old editorial on the Journal of the Royal Statistical Society (Zidek, J. (2006) Editorial: (Post-normal) statistical science. Journal of the Royal Statistical Society, Series A, 169 (1), 1–4) which advocated this kind of hybridization. See also Saltelli, A., 2016, "Young Statistician, You shall live adventurous times", *Significance* (The Royal Statistical Society), December 2016, Volume 13, Issue 6, (pages 38–41).

The participation of Jeroen van der Sluijs ensures that many years of experiences in the use of methods for quality of quantitative information, including close collaboration with real-life application in science-governance institutions such as the Netherlands Environmental Assessment Agency, will provide a good input of methods and test cases, see references at www.nusap.net.

This ambitious project partly fulfils public pledges made by the proponents to improve the quality and use of quantitative information, see, e.g., Stark, P., Science is "show me," not "trust me," December 31, 2015, The Berkeley Initiative for Transparency in the Social Sciences, http://www.bitss.org/2015/12/31/science-is-show-me-not-trust-me/; Stark, P., 2015, Pay No Attention to the Model Behind the Curtain, https://www.stat.berkeley.edu/~stark/Preprints/eucCurtain15.pdf; and Saltelli, A., Giampietro, M., Ravetz, J.R., 2016, Decalogue of the diligent quantifier. A Pledge, http://www.andreasaltelli.eu/file/repository/Decalogue_of_the_diligent_quantifier_online_Versio n_2.pdf.

The project has the potential to make a significant contribution to SA by ensuring that proper craft skills are cultivated among practitioners through appropriate teaching materials. The brand name of the Centre for the Study of Science and the Humanities of the University of Bergen, of the Division of Biomechanics, Department of Structural Engineering of Trondheim and of Berkeley's Division of Mathematical and Physical Sciences, Department of Statistics, and the Berkeley Institute for Data Science (BIDS) ensures that their joint syllabus in this crucial area of applied statistics will be read, studied and adopted broadly. The three institutes already cooperate on EU bids (e.g. one on sensitivity analysis still being evaluated) and projects (one on complexity science and the study of the nexus water, energy and land use–Bergen and Berkeley– already funded). This the project has a high degree of likelihood of obtaining complementary

funding from other sources beyond the Centre as the participating actors mean and intend to work together. Stark leads the BIDS working group on Reproducibility and Open Science and collaborates actively with faculty at University of Washington and NYU on curricula for reproducibility through the Moore/Sloan Data Science Environments grant. Pedagogy and software modules developed under this grant are likely to be adopted by UW and NYU as well.

Examples of teaching material

Andrea Saltelli: from sensitivity analysis to ethics of quantification in a short three day course:

> Course at ICTA: 'Sensitivity analysis, sensitivity auditing and beyond'; Lesson 1: Sensitivity Analysis ,
> http://www.andreasaltelli.eu/file/repository/Saltelli_Bellaterra_Sensitivity.pdf
>
> Course at ICTA: 'Sensitivity analysis, sensitivity auditing and beyond'; Lesson 2: Sensitivity Auditing ,
> http://www.andreasaltelli.eu/file/repository/Saltelli_Bellaterra_Auditing.pdf
>
> Course at ICTA: 'Sensitivity analysis, sensitivity auditing and beyond'; Lesson 3: Ethics of quantification ,
> http://www.andreasaltelli.eu/file/repository/Saltelli_Bellaterra_Ethics.pdf

Leif Rune Hellevik: A notebook in Python

> A Jupyter/IPython notebook for a practical introduction to Sensitivity Analysis.
> https://github.com/lrhgit/uqsa_tutorials/blob/master/sensitivity_introduction.ipynb

Jeroen van der Sluijs: Knowledge quality assessment

> Open access course module in Knowledge Quality Assessment
> (https://proxy.eplanete.net/galleries/broceliande7/KQA)

Philip B. Stark: nonparametrics, uncertainty quantification

> Short course on nonparametric inference in auditing and litigation
> https://github.com/pbstark/MX14
>
> Teaching materials for nonparametric statistics https://github.com/pbstark/Nonpar

TIMELINE and MILESTONES

Summer 2017: Identify four key examples and data sets from a spectrum of applications. Develop workflows and processes for collaboration using GitHub, Jupyter notebooks, and other tools. Recruit graduate student researchers from the participating universities.

Fall 2017: Berkeley visit by Norwegian faculty. Outline the contents of the Jupyter notebooks. Guest lecture(s) by Norwegian faculty in Berkeley Statistics 159/259. Begin coding, including developing appropriate unit tests, coverage tests, and regression tests. Begin to architect a Python package of utility "building blocks" for SA, including identifying core functionality.

Winter 2017-2018: Complete Jupyter notebooks for the first case study/exemplar. Improve architecture of the Python package for SA.

Spring 2018: Norwegian visit by Berkeley faculty. Lectures/workshops in Bergen by Berkeley faculty. Complete Jupyter notebook for the second exemplar.

Summer 2018: Complete remaining Jupyter notebooks. Abstract common functionality into final version of the Python package, re-factoring as necessary; publish the package, with associated tests, on Pypi. Disseminate results.

PROJECT PARTICIPANTS AND THEIR ROLES (Attach brief (1-2 pages) CV of PIs)

PIs will share responsibilities equally, but all have different expertise. They will collaborate closely to develop the Jupyter notebooks, including weekly meetings using Google Hangouts, including the PIs and the graduate students working on the project. Each investigator will supervise a graduate student at his home institution on work on this project.

PHILIP B. STARK

Professional Preparation

A.B., Philosophy, Princeton University, 1980.
Ph.D., Earth Science, U.C. San Diego, 1986.

Appointments

Associate Dean, Division of Mathematical and Physical Sciences, U.C. Berkeley, 2015–present
Velux/Villum Visiting Professor of Theoretical Computer Science, IT University of Copenhagen, 2016
Chair, Department of Statistics, U.C. Berkeley, 2012–2015
Director, Statistical Computing Facility, U.C. Berkeley, 2012–present
Vice Chair, Department of Statistics, U.C. Berkeley, 2011–2012
Acting Chair, Department of Statistics, U.C. Berkeley, 7–8/2011
Senior Data Science Fellow, Berkeley Institute for Data Science, 2014–present
Affiliated Faculty, Simons Institute for the Theory of Computing, U.C. Berkeley, 2014–present
Affiliated Faculty, Berkeley Food Institute, U.C. Berkeley, 2014–present
Faculty, Designated Emphasis in Computational Science and Engineering, U.C. Berkeley, 2008–present
Faculty Assistant in Educational Technology, U.C. Berkeley, 2001–2003
Professor, Department of Statistics, U.C. Berkeley, 1998–present
Visiting Associate Professor, School of Mathematical Sciences, Tel Aviv University, 6/1996
Associate Professor, Department of Statistics, U.C. Berkeley, 1994–1998
Assistant Professor, Department of Statistics, U.C. Berkeley, 1988–1994

Awards and Fellowships

2015: Leamer-Rosenthal Prize for Open Social Science
2014: Fellow, American Statistical Association
2011: Chancellor's Award for Public Service, Research in the Public Interest, U.C. Berkeley
2011: John Gideon Award for Election Integrity, Election Verification Network
2006: Mellon Library/Faculty Fellow for Undergraduate Research
2003: Presidential Chair Fellow, University of California, Berkeley
1999: Elected Fellow, Institute of Physics
1999: Miller Research Professor, Miller Institute for Basic Research in Science
1989: Presidential Young Investigator
1987: National Science Foundation Postdoctoral Fellowship in Mathematical Sciences

10 Recent Publications

Luo, T., and P.B. Stark, 2015. Nine out of 10 restaurants fail? Check, please. *Significance, 12*, 25–29.

Saltelli, A., P.B. Stark, W. Becker, and P. Stano, 2015. Climate Models as Economic Guides: Scientific Challenge or Quixotic Quest?, *Issues in Science and Technology*, Spring 2015.

Matchett, J.R., P.B. Stark, R.A. Knapp, S.M. Ostoja, H.C. McKenny, M. Brooks, W. Langford, L.N. Joppa, and E. Berlow, 2015. Detecting the influence of rare stressors on rare species in Yosemite National Park using a novel stratified permutation test, *Nature Scientific Reports*, *5*. doi:10.1038/srep10702

Arratia, R., S. Garibaldi, L. Mower, and P.B. Stark, 2015. Some people have all the luck. *Mathematics Magazine*, *88*, 196–211. doi:10.4169/math.mag.88.3.196.c

Stark, P.B., 2015. Constraints versus priors. *SIAM/ASA Journal on Uncertainty Quantification*, *3*(1), 586–598. doi:10.1137/130920721

Mulargia, F., P. Gasperini, B. Lolli, and P.B. Stark, 2015. Purported precursors: poor predictors. *Bollettino di Geofisica Teorica ed Applicata*, *56*, 351–356. doi:10.4430/bgta0142

Regier, J.C. and P.B. Stark, 2015. Uncertainty quantification for emulators. *SIAM/ASA Journal on Uncertainty Quantification*, *3*, 686–708. doi:10.1137/130917909,

Boring, A., K. Ottoboni, and P.B. Stark, 2016. Teaching evaluations (mostly) do not measure teaching effectiveness, *Science Open*, `https://www.scienceopen.com/document/vid/818d8ec0-5908-47d8-86b4-5dc38f04b23e` (post refereed)

Mulargia, F., P.B. Stark, and R.J. Geller, 2017. Why is Probabilistic Seismic Hazard Analysis (PSHA) Still Used? *Physics of the Earth and Planetary Interiors*, *264*, 63-75.

Evans, S.N., R.L. Rivest, and P.B. Stark, 2017. Leading the field: Fortune favors the bold in Thurstonian choice models, *Bernoulli*, to appear.

Synergistic activities: *Structural*: Director of Statistical Computing Facility; Co-I, Berkeley Institute for Data Science, Co-I, Berkeley S-STEM grant; Faculty Advisory Committee, Berkeley Resource Center for Online Education (BRCOE); Faculty Advisory Committee, Athletic Study Center. *Educational*: Developed and taught course on Reproducible and Collaborative Statistical Data Science (2013); developed and taught hybrid courses at UC Berkeley from 1997 and Berkeley's first official online course 2007–, ported to Wave II of UC Online Education approved for credit throughout the UC system 2012–; co-developed (with Ani Adhikari) a sequence of edX MOOCs in introductory statistics, 2013–2014; developed SticiGui (`http://www.stat.berkeley.edu/~stark/SticiGui`), an integrated, interactive, dynamic textbook for introductory statistics used at about a dozen institutions. *Public service*: consultant for California and Colorado Secretaries of State; expert witness for USDOJ; testimony to state legislatures; Board of Advisors of U.S. Election Assistance Commission; extensive outreach to elections officials regarding Statistics.

Graduate advisor. Robert L. Parker (UCSD). **Postdoctoral advisor**. George E. Backus (UCSD)

Advising. *Current Ph.D. students* (2): Arturo Fernandez, Kellie Ottoboni *M.A. theses supervised* (5): Bendek Hansen, U. Michigan; Tian Luo, Bureau of Labor Statistics; K. Jarrod Millman, UC Berkeley; Jeffery Regier; Vincent Yates, Yammer. *Ph.D. dissertations supervised* (5): Imola K. Fodor, Genentech; Johann Gagnon-Bartsch, UC Berkeley; Christopher R. Genovese, Carnegie Mellon University; Niklaus W. Hengartner, Los Alamos National Laboratory; Bradley Luen; Chad M. Schafer, Carnegie Mellon University. *Postdoctoral scholars supervised* (5): Janne Huttunen, University of Auckland; Dmitry I. Nikolayev, Schmidt Institute for Physics of the Earth; R. Jay Pulliam, University of Texas; Karthik Ram, University of California, Berkeley; Daniel Turek, University of California, Berkeley

Curriculum vitae
PERSONAL INFORMATION
Family name, First name: Van der Sluijs, Jeroen P.
Researcher unique identifier(s) http://orcid.org/0000-0002-1346-5953
                            http://researcherid.com/rid/B-6302-2008
                            http://scholar.google.com/citations?user=B8VdMX4AAAAJ
Nationality: Dutch
Date of birth: 25 October 1965
URL for web site: http://www.uib.no/en/persons/Jeroen.P..van.der.Sluijs

- **EDUCATION**
1997   PhD – "*Anchoring amid uncertainty: On the management of uncertainties in risk assessment
            of anthropogenic climate change*" [Thesis **185x cited**, Google Scholar], Faculty of Science,
            Dept. of Science Technology and Society, Utrecht University, The Netherlands
1990   Master – Faculty of Chemistry, University of Leiden, The Netherlands

- **ACADEMIC QUALIFICATIONS**
2013   **Academic Leadership Trajectory** Utrecht University
2008   Senior Teaching Qualification Utrecht University (SKO)
2005   Senior Research Qualification Utrecht University (SKO)
2004   Certificate "Supervising & coaching of PhD students" (in-company training, Utr. Univ.)

- **CURRENT POSITIONS**
2014 – present **Full Professor** (100%) "Theory of Science and Ethics of the Natural Sciences", Centre for
            the Studies of the Sciences and the Humanities, **University of Bergen**, Norway
2011 – present **Associate Professor** (>2014: 20%) in "New and Emerging Risks"; Faculty of Geosciences,
            Dept. of Innovation, Environmental & Energy Sciences, **Utrecht University**, Netherlands

- **PREVIOUS POSITIONS**
2004–2012   Invited Professor; International Centre for Research in Ecological Economics, Eco-
            Innovation and Tool Development for Sustainability (REEDS); University of Versailles
            Saint-Quentin-en-Yvelines, France. (1^e classe du Corps Des Professeurs Des Universites)
2001–2011   Assistant Professor; Dept of Science, Technology and Society (STS), Utrecht University.
1997–2001   Lecturer/Researcher; Department of STS, Utrecht University, The Netherlands

- **FELLOWSHIPS AND AWARDS**
2015   **Ranked #25 in "The Sustainable 100"**, top 100 of most influential Netherlands persons
            contributing to sustainable development, by the daily newspaper *Trouw*;
2013   Nominated for Utrecht University Publi Award 2013 – **in top 3 of scientists with best
            media coverage** (TV, Radio & Daily newspapers) of Utrecht University. goo.gl/Awk3H9
1996   YSSP Fellow; International Institute for Applied Systems Analysis (IIASA), Laxenburg.

- **SUPERVISION OF GRADUATE STUDENTS AND POSTDOCTORAL FELLOWS**
8 PhD students (6 graduated, 2 ongoing); 7 PostDocs; 6 Junior Researchers; 17 MSc students (theses)

- **INSTITUTIONAL RESPONSIBILITIES & COMMISSIONS OF TRUST**
2007–present: Member of the "Health and Environment Surveillance Committee" of the **Netherlands
            Health Council** (members are **appointed by Royal Decree**; prestigious position)
2007–present: Member of the "Health and Environment Surveillance Committee" of the **Netherlands
            Health Council** (members are **appointed by Royal Decree**; prestigious position)
2011–2014: **Scientific Coordinator** international scientific Task Force on Systemic Pesticides
            (advising to IUCN & IPBES) Worldwide Integrated Assessment of the Impact of Systemic
            Pesticides on Biodiversity & Ecosystems [30 scientist from 15 countries, interdisciplinary]
2004–2014   **Co-led educational and research evaluations and audits at programme level, institute
            level** (Copernicus Institute UU), **and research school level** (SENSE Research School)
2004–2011   Member of the **Management Team** (MT) of the department of STS, Utrecht University
2001–2011   **Head of research cluster** "Energy and Global Change: Dealing with Risk and
            Uncertainty", department of STS Utrecht University
2011–2014: Member of Advisory Committee on Sustainability Issues to the Board (BAC) of the
            Association of the Dutch Chemical Industry (VNCI)

- **MEMBERSHIPS OF SCIENTIFIC SOCIETIES**

2009–present   **Society for Philosophy of Science in Practice** www.philosophy-science-practice.org
2005–present   **The Integrated Assessment Society** (TIAS) www.tias-web.info

- **MAJOR COLLABORATIONS**

Long-standing close collaboration with Utrecht University Copernicus Institute of Sustainable Development (2nd affiliation) and universities in: Oxford (Jerry Ravetz), Leeds (Suraje Dessai), Tokyo (Yuko Fujigaki), Kobe (Togo Tsukahara), Paris-Saclay (Martin O'Connor, Jean Paul Vanderlinden), London (UCL, Arthur Petersen), and: CSIRO Australia (James Risbey), Joint Research Centre (EC JRC) Ispra (Ângela Pereira), Centre National de la Recherche Scientifique (CNRS) Paris (Laura Maxim); European Environment Agency (EEA) (David Gee; David Stanners), Netherlands Environmental Assessment Agency (Peter Janssen).

- I have published in total **78 articles** in peer-reviewed journals and **30 book chapters**. My work has received **8056 citations** (Google Scholar).
- **5** papers **highly cited** (in **top 1%** of field & publication year)
- **h-Index**: **48** (Google Scholar); **32** (Scopus); **32** (ISI Web of Science) *(measured Feb 2017)*
- (Co-)organiser of more than 20 international workshops and conferences;

Funding 2005-2016: I (co)acquired and supervised (inter)national research projects from: EU FP6/FP7/H2020 [contributions to HEIRRI, EPINET, APHEKOM, GSD, INTARESE, ALARM, ERICA, PASARELAS]; Norwegian Research Council [UC4A, FiGo, UncAP]; Triodos Foundation [Ecological risks of systemic pesticides]; Knowledge for Climate (NL) [Decision making under uncertainty]; NL Food and Consumer Product Safety Authority [Risk assessment consumer products]; French Ministry of Environment [Toolkit for knowledge quality of endocrine disrupters' risk assessments]; Climate Changes Spatial Planning Programme (NL) [Framing climate change risk & benefits]; Netherlands Environmental Assessment Agency [Uncertainty in environmental assessment]; National Institute of Public Health and the Environment (NL) [Uncertainty in health risk assessment of electromagnetic fields]; Rathenau Institute (NL); [Consensus and dissent in the climate debate]; EC-JRC [Post Normal Science];

Selection of 10 representative publications as senior author:
1. **JP van der Sluijs**, M Craye, S Funtowicz, P Kloprogge, J Ravetz, and J Risbey (2005) Combining Quantitative and Qualitative Measures of Uncertainty in Model based Environmental Assessment: the NUSAP System. *Risk Analysis* 25 (2) 481-492
2. P Kloprogge and **JP van der Sluijs** (2006) The inclusion of stakeholder knowledge and perspectives in integrated assessment of climate change. *Climatic Change* 75 (3) 359-389
3. **JP van der Sluijs**, AC Petersen, PHM Janssen, JS Risbey and JR Ravetz (2008) Exploring the quality of evidence for complex and contested policy decisions. *Environmental Research Letters* 3 024008
4. JA Wardekker, A de Jong, JM Knoop and **JP van der Sluijs** (2010) Operationalising a resilience approach to adapting an urban delta to uncertain climate changes. *Technological Forecasting and Social Change* 77 (6) 987-998
5. L Maxim and **JP van der Sluijs** (2011) Quality in environmental science for policy: assessing uncertainty as a component of policy analysis. *Environmental Science & Policy* 14 (4) 482-492
6. AC Petersen, A Cath, M Hage, E Kunseler, and **JP van der Sluijs** (2011) Post-Normal Science in Practice at the Netherlands Environmental Assessment Agency. *Science Technology & Human Values*, 36 (3) 362-388
7. **JP van der Sluijs** (2012). Uncertainty and dissent in climate risk assessment, a post-normal perspective, *Nature and Culture* 7 (2) 174-195
8. M Chagnon, D Kreutzweiser, EAD Mitchell, CA Morrissey, DA Noome, **JP Van der Sluijs** (2015) Risks of large scale use of systemic insecticides to ecosystem functioning and services, *Environmental Science and Pollution Research* 22 (1) 119-134.
9. **JP van der Sluijs** and NS Vaage (2016) Pollinators and global food security: the need for holistic global stewardship. Food Ethics 1(1):75-91. doi:10.1007/s41055-016-0003-z
10. MM Haque, S Bremer, SB Aziz and **JP van der Sluijs** (2017) A critical assessment of knowledge quality for climate adaptation in Sylhet Division, Bangladesh. *Climate Risk Management* DOI:10.1016/j.crm.2016.12.002

Curriculum vitae of Andrea Saltelli, March 2016

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- **EDUCATION**

1976   Doctor Degree in Inorganic Chemistry (first of his course)
             Roma La Sapienza University, Italy
1976–1979   Studies in Physics
             Roma La Sapienza University, Italy

- **CURRENT POSITIONS**

2016 (Nov)-present: Adjunct Professor, Centre for the sciences and the Humanities, University of Bergen, Norway
2015–present Guest researcher Universitat Autònoma de Barcelona: Bellaterra, Catalunya, Spain

- **PREVIOUS POSITIONS**

1982–2015   Researcher, then Head of Unit (Econometrics and applied statistics), European Commission Joint Research Centre, Ispra, Italy
1980–1981   Fellow at the Argonne National Laboratory (Illinois, USA)
1977–1979   Fellow of the Italian Nuclear Authority, Rome

- **FELLOWSHIPS AND AWARDS**

2005 JRC best paper award (with three collaborators)
2006 JRC prize for best support activity.
2014 Delivered the Commencement speech at the faculty of Statistics, Berkeley

- **COLLABORATIVE RESEARCH PROJECTS LED BY APPLICANT**

I led about twenty activities of "Competitive Support". These are projects funded by a Commission service (e.g. employment or education of internal market) and executed by the JRC. At the time of leaving the JRC the average turnover of these projects exceeded M€2. I was also responsible for several Framework Programme projects (funded by the European Commission – DG Research) in the fourth, fifth, sixth, and seventh framework programmes (on business cycle analysis, flash GDP estimates, innovation measurements, etc.). In Spring 2016 I obtained a procurement from the European Commission to work on an econometric analysis of a regional statistics databases and in winter 2016 I submitted as coordinator a COST action on sensitivity analysis, evaluation pending.

- **TEACHING ACTIVITIES**

1995–2015   Ca. 30 summer schools on sensitivity analysis for international students
2005–2015   Ca. 10 summer schools on composite indicators (where I taught the content of the JRC-OECD handbook that I authored on the subject)
2009–2015   Sensitivity auditing courses twice a year for colleagues in the European Commission (part of a syllabus delivered by the EC Secretariat General).
2007–2009   Module on "Sensitivity Analysis" in PhD Courses Statistics University Bicocca of Milan (I)

- **ORGANISATION OF SCIENTIFIC MEETINGS**

Key organiser and creator of the series: International Conferences on Sensitivity Analysis (attendance from about 60 to about 150 in the time span)

- o Belgirate, Italy (25–27 September 1995),
- o Venice, Italy (19–22 April 1998),
- o Madrid, Spain (18–19 June 2001)
- o Santa Fe, New Mexico, USA (8–11 March 2004)
- o Budapest, Hungary (18–22 June 2007)
- o Milan, Italy (19–22 July 2010)
- o Nice, France (1–4 July 2013)
- o Reunion Island (1–4 November 2016)

Organiser of courses on sensitivity analysis (1995–present) and composite indicators (2005–2014).

- **INSTITUTIONAL RESPONSIBILITIES**

1994–1996   Member of the Scientific Committee of the Environment Institute of JRC
2002–2003   Member of the Scientific Committee of the Institute for the Protection and Security of the Citizen, JRC
1996–2005   Head of Sector the European Commission Joint Research Centre (Sensitivity Analysis)
2005–2015   Head of Unit in the European Commission Joint Research Centre (Econometrics and Applied Statistics)

Ten-year track record

I established and headed a unit at the Joint Research Centre (JRC) of the European Commission for Econometrics and applied statistics. The importance of our work is shown by the growing number of staff, which led to the unit being split into two in 2012 and continuing dynamic growth afterwards (80 people in the two units when I left in March 2015). The units acquired half of their budget from competitive funding from other services of the EC involved in Employment, Education, Internal Market and others. In March 2015 I retired to continue my research activity. Since retiring I published twelve among articles on academic and non-academic outlets, see http://www.andreasaltelli.eu/Articles. Since November 2016 I am adjunct professor at the University of Bergen.

I developed the discipline of sensitivity auditing with Silvio Funtowicz and trained colleagues from the EC in it, combining it with impact assessment methodologies. Sensitivity auditing has its root in sensitivity analysis, which I set out to unify through international conferences (so far there have been eight) and about ten summer schools mostly directed to young practitioners. Both series – organised in the last twenty years – are attracting increasing numbers of delegates. Together with my collaborators at the JRC and with the assistance of the OECD we systematised the **theory of construction of composite indicators**, linking them to such fields as multi criteria and decision analysis, and publishing an official guideline with the OECD, endorsed by the OECD High Level Statistical Committee (composed of 35 member states' official statisticians) in 2005. Two articles were published on the topic in the *Journal of the Royal Statistical Society*.

My role in this undertaking was to provide the link between indicators and policy, the use of Multi Criteria Analysis, and the drive to obviate the most evident shortcoming of composite indicators by creating a toolbox of existing and new statistical practices. University ranking was one of the often cited examples. The interplay between evidence and policy was a constant concern, leading to the development of sensitivity auditing as a discipline for the appraisal of evidence based on mathematical or statistical modelling feeding into the policy process. I am currently continuing my work of analytic critique of quantification, with three recent papers on the Ecological Footprint, and one on evidence based policy (see references). I am one of the principal investigator in REApprise, a project for the Norwegian SFF which passed phase one selection on March 15, 2016, see http://goo.gl/Nfra1C.

Summary of production and impact

In total I have authored:

- **99 peer-reviewed articles,** of which
- **37** in the **last 10 years**, of which
- **5** papers are **highly cited** (in **top 1%** of field & publication year; *ISI Essential Science Indicators*)

Performance indicators Saltelli (Nov 2015)

- I published recently two letters (correspondence) in *Nature*. One on the crisis of Science. (Ravetz R & Saltelli A, 2015 Policy: The future of public trust in science, *Nature* 524:161), and another in 2016 entitled 'Modelling: Climate costing is politics not science', Nature, 532, 177.
- I wrote a **book** "*Science on the Verge*" (2016) with Jerry Ravetz, Mario Giampietro and other scholars mostly from SVT Bergen.

Up to ten representative publications, from the last ten years, as main author

1. Saltelli, A. and Giampietro, M., 2017, What is wrong with evidence based policy, and how can it be improved? Futures, DOI: http://dx.doi.org/doi:10.1016/j.futures.2016.11.012.
2. Saltelli, A., Funtowicz, S., Giampietro, M., Sarewitz, D., Stark, P.B., van der Sluijs, J.P., 2016, Climate costing is politics not science, Nature, 14 April, 532, 177.
3. Saltelli, A., 2016, "Young Statistician, You shall live adventurous times", SIGNIFICANCE (The Royal Statistical Society), December 2016, Volume 13, Issue 6, (pages 38–41)
4. Giampietro, M., and Saltelli, A., 2014, Footprints to nowhere, *Ecological Indicators* 46, 610–621. **Cited 7x** *Scopus*; **15x** *Google Scholar*
5. Saltelli, A., Funtowicz, S., 2014, When all models are wrong: More stringent quality criteria are needed for models used at the science-policy interface, *Issues in Science and Technology*, Winter 2014, 79-85. **Cited 2x** *Scopus*; **24x** *Google Scholar*
6. Saltelli, A., van der Sluijs, J., Guimarães Pereira, Â., 2013, Funtowiz, S.O., What do I make of your Latinorum? Sensitivity auditing of mathematical modelling, *International Journal Foresight and Innovation Policy* 9 (2/3/4), 213–234. **Cited 5x** *Scopus*; **12x** *Google Scholar*
7. Paruolo, P., Saisana, A., Saltelli, A., 2013, Ratings and rankings: Voodoo or Science? *Journal Royal Statistical Society A* 176 (3), 609–634. **Cited 17x** *Scopus*; **72x** *Google Scholar*
8. Saltelli, A., M. Ratto, S. Tarantola and F. Campolongo, 2012 (Perennial Review of our 2005 paper), Sensitivity Analysis for Chemical Models, *Chemical Reviews*, 112 (5), pp PR1–PR21. **Cited 246x** *Scopus*; **378x** *Google Scholar* (2005 paper) 🏆 Highly Cited Paper
9. Saltelli, A., Annoni, P., 2010, How to avoid a perfunctory sensitivity analysis, *Environmental Modeling and Software* 25, 1508-1517. **Cited 177x** *Scopus*; **248x** *Google Scholar* 🏆 Highly Cited Paper
10. Saltelli, A., D'Hombres, B., 2010, Sensitivity analysis didn't help. A practitioner's critique of the Stern review, *Global Environmental Change* 20, 298-302. **Cited 8x** *Scopus*; **18x** *Google Scholar*

🏆 Highly Cited Paper *= received enough citations to place it in the top 1% of its academic field based on a highly cited threshold for the field and publication year. (ISI Essential Science Indicators)*

Books

Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, J., Gatelli, D. Saisana, M., Tarantola, S., 2008, Global Sensitivity Analysis. The Primer, John Wiley & Sons publishers.

Benessia, A., Funtowicz, S., Giampietro, M., Guimarães Pereira, A., Ravetz, J., Saltelli, A., Strand, R., van der Sluijs, J., 2016, Science on the verge, Published by The Consortium for Science, Policy and Outcomes at Arizona State University.

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Scientific publications

[1] V.G Eck, J. Sturdy, and L.R. Hellevik. Effects of arterial wall models and measurement uncertainties on cardiovascular model predictions. *Journal of Biomechanics*, 2016. Accepted.

[2] E. Boileau, P. Nithiarasu, PJ Blanco, LO Müller, FE Fossan, LR Hellevik, WP Donders, W. Huberts, M. Willemet, and J. Alastruey. A benchmark study of numerical schemes for one-dimensional arterial blood flow modelling. *Int J Numer Meth Biomed Engng*, 23, Jun 2015. Epub ahead of print.

[3] Vinzenz Gregor Eck, Wouter Paulus Donders, Jacob Sturdy, Jonathan Feinberg, Tammo Delhaas, Leif Rune Hellevik, and Wouter Huberts. A guide to uncertainty quantification and sensitivity analysis for cardiovascular applications. *Int J Numer Meth Biomed Engng*, jan 2015.

[4] V. G. Eck, J. Feinberg, H. P. Langtangen, and L. R. Hellevik. Stochastic sensitivity analysis for timing and amplitude of pressure waves in the arterial system. *International Journal for Numerical Methods in Biomedical Engineering*, 31(4):n/a–n/a, 2015. e02711 cnm.2711.

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[6] Paul R. Leinan, Torvid Kiserud, and Leif R. Hellevik. Human ductus venosus velocity profiles in the first trimester. *Cardiovascular Engineering and Technology*, 4(3):257–266, September 2013. Special issue on Fetal Circulation.

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