FOREKNOWLEDGE ASSESSMENT

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ANDRA
French national radioactive waste management agency

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KEYNOTE “SCENARIO FUTURES”

Peter Galison
Harvard University

PETER GALISON is the Joseph Pellegrino University Professor of the History of Science and of Physics at Harvard University; Galison’s work explores the complex interaction between the three principal subcultures of physics--experimentation, instrumentation, and theory. He is also greatly concerned with the impact of technology on the self, and how this influences science, policy, and development. With Robb Moss, he directed “Secrecy” (2008, 81 minutes) and recently completed “Containment” (2015, premiered at Full Frame), about the need to guard radioactive materials for the 10,000 year future. This film will be screened and discussed in a specific session on Wednesday afternoon.

Out of the Cold War and its nuclear armaments came a new form of coping with radical uncertainty: scenario futures, world as war game. Caught somewhere between apocalypse and bureaucracy, between science fiction and the big science, a new breed of Cold War futurists tried to narrate through terror to control. Back in the 1920s, scenarios were widely understood to be sketches of a larger story, glimpses, not a continuous dialogue or story. In the later part of World War II and then in the early Cold War, bit by bit these short-form story-ideas took hold as a way of outlining an event, a “what if” imagination of the results of a fundamentally disruptive accident, attack, embargo or invention in order to project possible futures. These sometimes cataclysmic reflections made their way into economic and natural earthquakes, culminating, (in terms of the degree of futurity) in the attempt to imagine the world 10,000 or even a million years from now—with the goal of warning our descendants--400 or even 40,000 generations from now about what we have done with our nuclear detritus.

SESSION 1 : Measured decision-making

Chair: Anne Bergmans

Anticipating, predicting, forecasting? Comparing and understanding forms of foreknowledge in policy

David Demortain[1*]
INRA, UMR 1326 Laboratoire Interdisciplinaire Sciences Innovations Sociétés (LISIS), 77454 Marne-La-Vallée, France.
[*] *E-mail: demortain@inra-ifris.org*

In recent years, foreknowledge has seemingly emerged as new domain of knowledge and of knowledge-for-policy. This domain has its own identifiable techniques, dedicated research groups, and materializes by the routine production and use of knowledge in policies. However, the designation of foreknowledge - anticipation, prediction, forecasting, foresight... - varies over time, as well as within and across areas of application, with the same notions employed in different fields sometimes meaning opposite things, and different notions covering essentially similar practices. This diversity obscures the mechanisms behind the supposed rise of foreknowledge. An assumption one can make is that this diversity reflects the fact that policy-making and governance, in particular sectors, has become a space of production of foreknowledge; one in which its norms and forms are articulated. For that reason, foreknowledge varies: it reflects these sectoral or local policy epistemologies. This is the hypothesis that the paper tests. The paper draws from research conducted within the context of the ANR-funded project Innox[1].

Forms of foreknowledge in three different policies

The paper draws on a comparison of the forms of foreknowledge within and across three different areas -- crime prediction; energy scenarios; predictive toxicology -- spanning a large set of disciplines, of systems modelled (social; physical or biological systems) and of kinds of policy and politics, to make sense of why and how a given form of foreknowledge takes hold at a given moment in time and in a given context.

Energy systems modeling, predictive policing or computational toxicology are, in and of themselves, open and rich fields of research and practice. While there are iconic techniques spearheading each of these fields, they remain very diverse and dynamic. Providing a neat definition of these expertises is a major challenge. Most of those who attempt to provide just such a definition partake in an effort to identity and promote these fields, and particular orientations within these fields.

A bibliometric study of energy technologies/systems modeling shows that the dominant language therein is one of modeling to support forecasting of energy production and consumption, and elaboration and choice among scenarios or plans [1]. Various techniques comprise the field of energy modeling and forecasting, which is an already old tradition in economics and engineering. The models that are most used in policy-making arenas are the method of integrated assessment, much used in the context of GIEC; BU and TP models, used in national energy policy making. There are platforms for validation and comparison of models available, which become in and of themselves one of the spaces in which energy and climate policies are designed [3].

The field of research in predictive policing encompasses two broad techniques [2]: crime simulation, underpinned by agent-based theories for social simulation of the behavior of crime offenders; the other part of the field invests in the mining of crime data compiled by policy forces and Courts, by means of algorithms. The first field is, historically, a specialization of criminologists. The second is a field that is developed, in part, by so-called “data scientists”.

The field of computational toxicology, finally, develops at the intersection of toxicological modelling (the combination of statistical/mathematical approaches to biochemical processes) and computing skills. There are three broad applications, the first two being already in use in policy, through “risk assessment” [4]. One is pharmaco- or toxicokinetics, that is the study of the fate of chemicals in the human body by means of mathematical biological models of the human body. The other is the

[1] Innovation in Expertise : Modeling and Simulation as Tools of Governance, ANR-13-SOIN-0005

structure-activity relationship field, where increasingly large databases of experimental results are mined to produce statistical and mathematical formulas capturing the relation between a chemical structure and a type/level of toxicity. The third broad area is the production of large databases of biological activity, resulting from screening of the activity of chemicals in the proteome, metabolome or else, resulting in the visualization of networks of biological activity.

Comparing discrete fields of computational modeling

One of the ways of handling the comparison between these dissimilar fields is to trace the mathematical, statistical or quantitative techniques more generally, that they employ, some of which are generic. Agent-based simulation, for instance, or genetic algorithms, can be found in each. Such an approach would produce a classification of techniques pertaining to the field, and help track which get used in policy-making, and which aren't used. One of the problems which we have using such classification is that it assumes the stability and standardized nature of these techniques, whereas we know that they may change a lot depending on who is performing them and in what context. Furthermore, computational modeling, clearly, emerges at the intersection of pre-existing models or families of models developed within the field of specialization (e.g. QSAR models emerged in chemistry in the early XXth century), and subsequent computerization.

Thus, a better way of analyzing these expertises is to analyse trajectories of computerization, and what it owes to the policy-making or governance context. The current discourse on the rising computing capacities put the stress on the availability of technologies to perform computations rapidly and iteratively. Computation, in this sense, relates to computerization. But computation, of course, pre-existed whatever computing technology. In a simpler sense, computation relates to the performance of a calculation, based on the use of some (at first simply 'mental') algorithm, or set of operations. Sociologists have shown, in various contexts, that the current times are characterized not just by the rise of calculation, but by the combination of three things:

- Calculation itself, namely the algorithms it is enabled by
- Data and databases
- The material infrastructure to perform calculations using these data, and to circulate the product of these calculations (that may be other things than just numbers: visualizations, graphs are important there too).

If we follow Mary Morgan and the philosophers and historians of modeling more generally, we know that something inherent in model is that they are a heuristic for guiding further investigation; it is a mediation in the production of more accurate knowledge, to either refine a theory or explore data. In this sense, a model incorporates a realistic concept of the targeted system, the system that is ultimately being investigated. In the kind of computer simulation that economics perform, this is the "game" of game theory [5].

So, to be complete, we should consider that computer simulation and prediction is the result of a technological assemblage of 1/ a model/algorithm (one equation or set of equations); 2/ data (including an infrastructure to produce, curate, store, share this data); 3/ IT tools to work with, analyze, visualize, transport the data and the simulations; 4/ a concept that is the foundation for analogical models, mediating the reality being investigated. The assemblage is cognitive: there are categories at each level, which need to be aligned. It is also social: there are people behind the calculation, the production of the data and the production and running of computers; an assemblage spans social boundaries between groups.

The assemblage of computational modeling: political contexts

What I will assume, then, is that each of the policies in question has witnessed the rise of such an assemblage; this is the common outcome that can be observed across all three cases. Which leads to the following question, as concerns policy and governance: how does the shape of policy-making and policy action in all three cases influence the ways in which this assemblage is being made?

Across all three cases, there are important differences, and some similarities. Major differences include the type of policy intervention, the governmental actor, the geographical configuration of this intervention, but also, more directly related to computation and prediction, the time horizon of the policy intervention and the temporal pattern of policy action. Another key source of differentiation among three cases is the pattern of relations between providers of computing skills and infrastructures and institutions, and the nature of these providers. Energy and chemicals are areas where the majority of these providers originate from the academic field. In predictive policing, the field is structured by the emerging private, commercial actors that develop tools with strong marketing claims for difference and superiority.

There are few, if any, strict similarities between all three cases, but they are comparable at several levels (e.g. databases (of energy consumption, of committed crimes, of experimental results) existed and are accessible, and could be expanded more or less seamlessly; the owners of models were already present and legitimate in policy-making circles… The presentation will expand on these similarities which, in Ragin's case-based qualitative strategies methods [6], should point to the mechanisms of emergence of computational modeling. Particular attention will be paid to the nature of the problem of uncertainty in these contexts, whether and how they differ among the three areas.

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Nanomedicines: addressing uncertainties from bench to bedside

Hervé Hillaireau
Institut Galien Paris-Sud, Univ. Paris-Sud, CNRS, Université Paris-Saclay, Châtenay-Malabry, France

One of the major obstacles to drug efficacy is the nonspecific distribution of the biologically active compound after administration. This is generally due to the fact that the drug distributes according to its physicochemical properties, which means that its diffusion through biological barriers may be limited. In addition, some chemical entities are either rapidly degraded and/or metabolized after administration (peptides, proteins, and nucleic acids). Based on these observations, the idea has emerged that nanotechnologies may be employed to modify or even to control the drug distribution at the tissue, cellular or subcellular levels.

Among the technologies investigated for drug targeting since the late 1970s, liposomes and polymer-based nanoparticles have led to the major developments in the field. Liposomes and nanoparticles may be defined as being submicron (<1 μm) colloidal systems composed of phospholipids and polymers, respectively, generally biocompatible and biodegradable. Such colloidal systems, with a size 7 to 70 times smaller than the red cells, may be administered intravenously without any risk of embolization.

One of the major applications that takes advantage of the preferential location of nanoparticles in the liver macrophages following intravenous administration is the treatment of hepatic tumors using polyalkylcyanoacrylate nanospheres. Kupffer cells are indeed major sites of accumulation of such particles. Thus, in a murine histiocytosarcoma hepatic metastases model, doxorubicin-loaded 200-300 nm nanospherses have proven superior to the free drug in terms of efficacy, reduction of cardiac toxicity and reversion of resistance. Kupffer cells were found to act as a reservoir allowing slow diffusion of doxorubicin towards tumor cells, as a result of particle biodegradation. This nanomedicine is currently tested in clinical trials under the name of Transdrug®.

A great deal of work has also been devoted to developing nanoparticles and liposomes that are "invisible" to macrophages. A major breakthrough in the field consisted in coating nanoparticles with poly(ethyleneglycol) (PEG), resulting in a "cloud" of hydrophilic chains at the particle surface, which repels plasma proteins. These "sterically stabilized" nanocarriers have circulating half-lives of several hours, as opposed to a few minutes for conventional ones. They have been shown to function as reservoir systems and can penetrate into sites such as solid tumors. The main success in their use as nanocarriers relates to the delivery of doxorubicin using PEGylated liposomes, approved as Doxil® for the treatment of some ovarian cancers. Their efficacy originates in their ability to escape phagocytosis and extravasate selectively through the fenestrated and leaky vasculate that generally characterize tumor vessels (known as “enhanced permeability and retention” effect).

In conclusion, the brief history of nanomedicine, from chemical, physico-chemical and biological studies, both *in vitro* and *in vivo*, to clinical trials in humans and finally approved drug products, illustrates the need to conduct multidisciplinary research in a convergent way. This can be seen as way to address uncertainties in systems as complex as a human body interacting with a therapeutic material.

"If honestly done, there are no bad predictions in crime control". Predicting the "unforecastable" in police patrols.

Bilel Benbouizd
Maître de conférences, UPEM, LISIS

The machine learning algorithms of "big data" find applications in all spheres of society. In this supposed "data revolution", the security sector has an important place. The notion of predictive policing means a new era in which the police in the United States could now anticipate crimes through the machine learning methods. For three years, I investigate the world of "predictive policing" in the United States and France, in particular from interviews with crime analysts in the police, data scientists and business stakeholders.

Softwares indicate to police patrols the location of future crimes (burglary, car theft, homicide, etc.) with a stunning accuracy (boxes of 250m x 250m on the map). However there are few situations where the police can directly observe a criminal event, even when discreet plain clothes officers are positioned on the indicated areas. So, how can we claim "predict" crime? Why should we use predictive software that does not allow prediction? On what condition is a crime prediction successful?

A comment made by a crime analyst at Philadelphia Police Department outlines what "prediction" means for the police: "If honestly done, there are no bad predictions in crime control". This idea, often repeated by security experts, means that the prediction is not expressed in terms of right or wrong, but good or bad. The prediction of data scientist is neither knowledge nor information: it is a technique that makes sense as far as it act on the police organization. It's why some experts (but not the majority) are considering predictive policing as "forecasting" and not "predicting" (difference between "to forecast" and "to predict" is a classical discussion in the field of risk prevention). But, the semantic shift from forecasting to predicting that appeared recently should be taken seriously: predicting is no longer a subset of forecasting, but a practice that make "activity" possible in "unforecastable" situation. The problem is not to believe or not to believe, but to adhere to the values conveyed by the recommendations of the algorithms.

In this presentation, we want to show that the prediction algorithms are part of the production of inspirational utopias (utopies mobilisatrices). The thesis which will be defended is that the "predictability" of crime is an "actionable myth" (un mythe opératoire) that replaces the myth of "forecasting". Paradoxically, the "utopia of prediction" can act on "unforecastable phenomena". We analyze two competing American companies: Predpol and Azavea (Hunchlab software). From these two cases, we explain the paradox of predicting the unforecastable. Prediction can act in a situation of "unforecastibility" because manufacturing software for government raise creative tensions that promote "policy settings" translated in the algorithms, the choice of data and the possibilities offered by the "administrator" systems of the software. The differences between Predpol and Hunchlab show the specific way to do politics with predictive analytics software.

BIOGRAPHY

Bilel Benbouzid est Maître de conférences à l'Université Paris Est Marne la Vallée, au Laboratoire Interdisciplinaire Science Innovation Société (LISIS). Ses recherches portent sur le statut du savoir dans le gouvernement de la sécurité, dans une perspective de sociologie des sciences. Il a soutenu sa thèse en septembre 2011 sous le titre "La prévention situationnelle : genèse et développement d'une science pratique". Il codirige actuellement le projet "Innovation dans l'expertise ?" (INNOX), financé par l'Agence Nationale de la Recherche, visant à examiner comment et dans quelle mesure la modélisation et la simulation numérique deviennent une forme d'expertise mobilisée dans l'action publique pour prédire, anticiper ou prévoir.

Framing epistemic uncertainties through bounding strategy in risk assessments. Examples of natural hazard and geological storage of CO_2

Jeremy, Rohmer[1*], Annick Loschetter[1], Jean-Charles Manceau[1], Behrooz Bazargan[1,2]
[1]BRGM, 3, av. Claude Guillemin, BP 36009, Orleans, Cedex 2, France
[2]Ecole des Mines de Nancy, Campus ARTEM, CS 14234, 54042 Nancy, France

[*]*E-mail: j.rohmer@brgm.fr*

INTRODUCTION

Distinguishing between two facets of uncertainty has become a standard practice in natural hazard and risk analysis (e.g., [11] and references therein), namely:

- Aleatory (aka randomness) is inherent to the physical environment or engineered system under study and represents its intrinsic variability;
- Epistemic uncertainty is not intrinsic to the system under study and can be qualified as being knowledge-based, because it stems from the incomplete/imprecise nature of available information, i.e., the limited knowledge on the physical environment or engineered system under study.

For representing aleatory uncertainty, there is a large consensus in the community about the use of probabilities under the frequentist perspective: when a large number of observations are available, probability distributions can be inferred. An example is the fit of power-law to the relationship on frequency-volumes of cliff rockfalls [5]. However, for representing epistemic uncertainty, no unique straightforward answer exists.

In situations where the resources (time and budget) for hazard and risk assessments are limited, and where the available data are imprecise, incomplete, fragmentary, vague, ambiguous, etc., the challenge is to develop appropriate mathematical tools and procedures for "accounting for all data and pieces of information, but without introducing unwarranted assumptions" [4].

In such highly constraining situations, probabilistic alternatives to the frequentist approach rely on the use of Bayesian methods: this allows mixing subjective and objective information, i.e. perception regarding a probabilistic model, and observations/data for model update. In this approach, a unique probability distribution represents the expert' state of knowledge. However, this may appear debatable in the phase of information collection, i.e. in the early phase of uncertainty treatment: subjectivity is introduced at "the very beginning of the risk analysis chain, whereas it would make more sense to appear at the very end to support decision-making" [7].

Alternatives to the probabilistic setting (frequentist or Bayesian) for representing epistemic uncertainties have been developed: those new uncertainty theories are termed extra-probabilistic (e.g. [1,7]), because their basic principle relies on bounding all the possible probability distributions consistent with the available data [3,7] instead of *a priori* selecting a single one.

The present communication focuses on the use of (nuanced) intervals (*aka* possibility distributions) for representing and framing epistemic uncertainties. In the following, we first describe a motivating case in the domain of risk assessment for CO_2 geological storage [10]. The oral presentation will also address other examples in the field of natural hazards [5]. Then, we briefly describe the principles underlying the possibility distribution. Finally, we analyse the pros and cons of mixing different uncertainty representation tools from a decision-making perspective.

CASE STUDY IN THE DOMAIN OF CO_2 STORAGE

CO_2 capture and storage technology aims at storing CO_2 permanently in appropriate deep (usually > 800 m) geological formations like saline aquifers [9]. In the present study, we focus on a potential (real but fictive) storage site in the Paris basin (France) described by [10] and references therein. A possible risk is related to the leakage of reservoir resident fluid (brine) through an abandoned well from the reservoir aquifer to the shallow potable water aquifer of the Albian rock formation. Though plugged wells are considered well localized, in some cases very little information is available about their characteristics.

The study is based on the flow model described by [10] and references therein. The input model parameters correspond to the reservoir formation's properties, initial conditions, injection scenario, leakage characteristics, shallow potable aquifer's properties, etc. Data availability and quality differ from one parameter to another. In particular, reservoir properties are relatively well documented, which leads us to use probability distributions inferred from available data, whereas leakage pathway's characteristics and shallow aquifer's properties are poorly known: the available data often restrict to bounds (min-max) and to a most likely value provided by experts. For instance, the best estimate of the potable aquifer's permeability ($\log_{10}$) should be -11.1 with possible high values up to -10.9 and low values down to -12.1. A pure probabilistic approach would lead selecting a unique probability distribution in the form of a triangular probability distribution. Yet, by doing so, additional information is added by making assumptions on the probability values within these bounds, which may not be justified given the situation of poor knowledge.

REPRESENTING USING POSSIBILITY DISTRIBUTIONS

An alternative relies on the use of only intervals, which is the simplest approach for representing imprecision. In our case, experts may provide more information by expressing preferences inside this interval, i.e. the interval can be "nuanced". Experts' preferences inside this interval can be conveyed using possibility distributions [3,6], which describe the more or less plausible values of some uncertain quantity. In the aquifer's permeability example, the expert is certain that the value for the model parameter is located within the interval [-12.1;-10.9]". However, the expert may be able to judge that "the value for the model parameter is most likely to be -11.1". The preference of the expert is modelled by a degree of possibility (i.e. likelihood) ranging from 0 to 1.

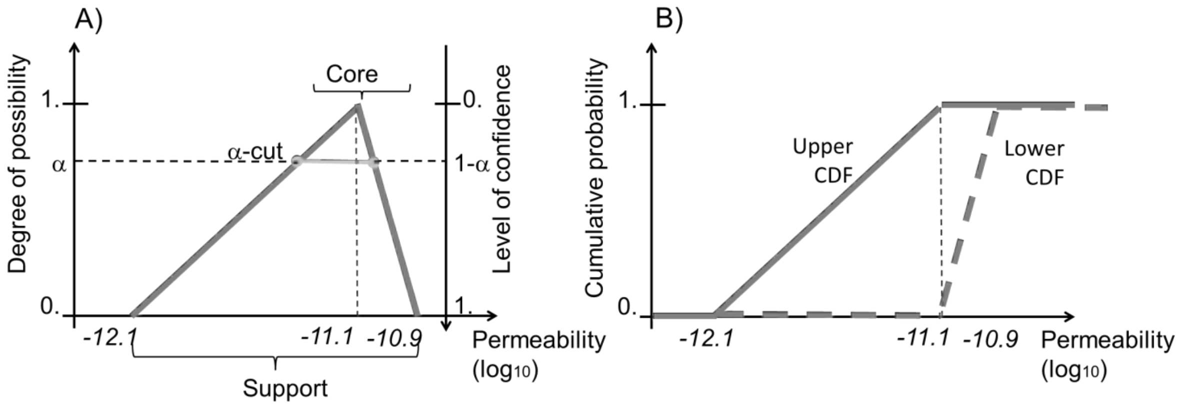

Figure 1: A) Definition of a possibility distribution. B) Translation of the possibility distribution in a set of cumulative probability distributions CDFs bounded by an upper and a lower distribution.

In practice, the most likely value of -11.1 ("core", Fig. 1A) is assigned a degree of possibility equal to one, whereas the "certain" interval [-12.1 ; -10.9] ("support", Fig. 1A) is assigned a nil degree of possibility, such that values located outside this interval are considered impossible. Linear segments are usually selected for the left and right sides of the possibility distribution.

Though the possibility distribution shares the same form as the triangular probability distribution, it should not be confused: the possibility distribution actually encodes the set of all probability distributions (CDF in Fig. 1B) which are consistent with the available data (min-max and best estimate). This set is limited by an upper and a lower probability bounds (Fig. 1B).

UNCERTAINTY PROPAGATION AND DISCUSSION

A transparent message on epistemic uncertainty…

Uncertainty propagation aims at estimating the impact of the input uncertainty on the model output (here the volume of leaked brine). In a pure probabilistic framework, the uncertainty propagation can rely on Monte-Carlo-like sampling procedure. The result can be represented in the form of a CDF (dashed line in Fig. 2) to evaluate: 1. the quantile at 95% (Q_{95}=640 m^3) and 2. the probability P that the volume of leaked brine might exceed a given threshold (vertical line in Fig. 2). The pure probabilistic propagation gives a result which is largely below the threshold and would lead to consider the risk level as acceptable.

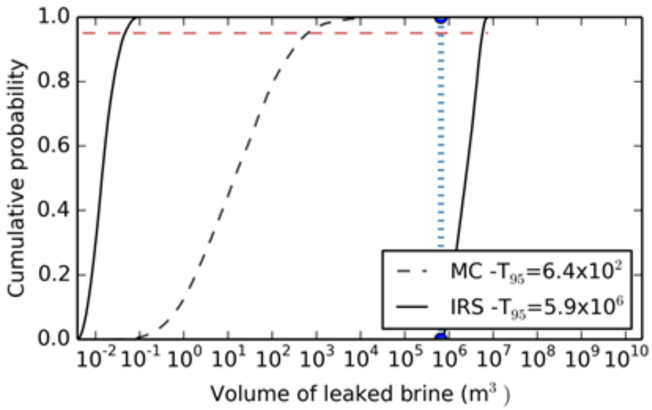

Figure 2: Comparison of uncertainty propagation results obtained in the probabilistic framework (label "MC", dotted line) and in the possibilistic-probabilistic framework (label "IRS", full lines), adapted from [10].

On the other hand, using different tools (probability and possibility distributions) for representing epistemic uncertainties imposes using propagation procedures which mix Monte-Carlo-like sampling and interval-based calculation approaches [3,7]. In this hybrid situation, the result of the uncertainty propagation cannot take the form of a single CDF: the final CDF is ill-known, because some uncertain parameters could only be bounded. Due to this imprecision, the result takes the form of a set of CDFs bounded by an upper and a lower distribution (straight black line in Fig. 2). Here, Q_{95} is not a crisp value but is bounded by $8.1e^{-2}$ and $5.9e^{6}$ m^3. The gap between both quantile bounds exactly represents "what is unknown": data scarcity on uncertain parameters leads to a situation of very high level of epistemic uncertainty, which is hidden in the format of the pure probabilistic result (crisp value).

Considering the probability of exceedance, P is here bounded by 0 and 1. This prevents any decision regarding the acceptability of the leakage risk contrary to the pure probabilistic treatment, which clearly leads to excluding the risk. By providing a single value, the probabilistic result gives a false impression of confidence, which has been criticized in the statistical literature [1,3,6,7], but also by end-users of risk analysis: as pointed out by [8], many decision-makers of ATC Project 58 state that, ''Guideline for seismic performance assessment of buildings" would "prefer a statement of confidence in the results of the risk assessment, particularly if the consequences are severe". One way to provide this statement of confidence is through an interval estimate of the probability of exceedance.

… which should be cautiously conveyed.

The other side of the coin is the level of sophistication added by the bounding strategy (e.g., [1,2]). Bounded probabilities can appear to be less transparent than those of probability: the danger is to add more confusion than insights [2]: decision-makers may not feel comfortable in using such a format. Should the most pessimistic value, say the lower bound, be used? If so, the more optimistic values are neglected. Otherwise, should the average value be used?

Bounded probabilities may be sufficient for "fulfilling the transparency requirement of any risk assessment", but not "to achieve the level of confidence necessary for assisting the deliberation process and decision making" [2]. If the message conveyed by the probability bounds is not transferred cautiously from scientists to end-users, this might undermine the confidence in the risk analysis, potentially leading to a loss of credibility in the results. The situation of large degree of epistemic uncertainty is obviously hard to communicate. From a pure technical perspective, this outlines the flaws in the assessment process: extra-probabilisitc methods enable a robustness assessment and a critical review fo the risk chain analysis, e.g. [1]. But outside the scientific community, this may be mistaken as a situation where nothing is known and could underpine the role of the expert.

SUMMARY

The case study used in this study is extreme and primarily serves to outline the consequences of the assumptions made for uncertainty treatment (uncertainty termed as ontological). Complements and synergies between the different settings (extraprobabilistic, frequentist, Bayesian) should be sought: a possible code of practice shared by all practitioners as well as a comprehensive terminology to convey the uncertain results are thus desirable in the future.

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The 1.5° long-term global temperature goal in climate regime. Debate on dangerousness, political legitimacy and feasibility.

Hélène Guillemot
Centre Alexandre Koyré

The mention of a 1.5° long-term temperature target in the Paris agreement at COP 21 in december 2015 was almost unanimously welcomed by state delegations and NGOs; however it surprised many climate scientists. According to model-based scenarios, limiting warming to 2° (the previous commitment, adopted at Copenhagen COP 15 in 2009) would not only imply immediate and drastic cuts in CO2 emissions at a global level, but moreover it would require the removal of CO_2 from the atmosphere through "negative emissions" technologies that currently do not exist on the required scale, and that may create adverse effects. As greenhouse gas emissions continued to grow, the 2° target is increasingly inaccessible; and yet in Paris an even more stringent objective was being proposed. How should we understand the success of an arguably unattainable target?

From a political perspective, it shouldn't come as a surprise, since the 1.5° target results from years of efforts by highly determined actors. But while 1.5° is a political target, it is based on scientific research and is criticized by other scientific publications. Thus the 1.5° target revealed disagreement in a domain where previously, scientific consensus was publicly expressed. Neither purely scientific controversies nor political disputes, the disagreements on long-term temperature goals sit at the boundary between these domains, and can be seen as reflecting a transformation in the science-politics relations in the climate change problem.

Since the beginning of the climate regime in the late 1980's, the relation betwwen science and politics has been summarized by the formula "science speaks truth to power" : science is supposed to be the principal authority that justifies political action. This consensual and hegemonic framing was backed by a broad coalition of actors (scientists, journalists, NGO…) even if, according to some social scientists, it leads to polarize debates aroud science rather that around polical responses. But the Copenhagen COP in 2009 challenged this framing; as negotiations failed, it became clear that scientific consensus is not enough to trigger political action. After the failure of 20 years of "top-down" strategy, with burden sharing and legally binding reduction targets, in Copenhagen a "bottom-up" approach was adopted: the "pledge and review" system, wherein countries set their own emissions reductions commitments. But the Copenhagen COP also delivered a "top-down" innovation: the goal of limiting global temperature increase to 2°. In 1990, Article 2 of the Climate Convention defined an "ultimate objective": "to achieve (…) stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system ", but it didn't specify this "dangerous" level. It was in the 2000s that the long-term goal took on its central role in the IPCC reports and in climate negotiations. The 2° target came to dominate in the months leading up to the Copenhagen conference.

The result of a political and scientific co-construction, the 2° threshold benefited from a clear legitimacy. However, certain groups were pushing for a more "ambitious" target: the Alliance of Small Island States (AOSIS), along with the group of Least Developed Countries (LDC), supported the targets of 350 ppm CO_2 and 1.5° of warming. When the 2° target was adopted, these countries, grouped together in the Climate Vulnerable Forum, succeeded in pushing for the Copenhagen Declaration to call for "strengthening the global long-term goal during a review by 2015, including in relation to a proposed 1.5°C target." Thus the issue of the 1.5°C target was in the making at the Copenhagen COP.

Between the COPs in Copenhagen in 2009 and in Paris in 2015, the 2° target was constantly reaffirmed in climate arenas, but a much wider range of views was expressed in scientific journals. Some articles and reports warned of the challenge of reversing the trend of emissions for attaining the 2° target, but other scientific publications concluded that 2°C was attainable. Indeed, as greenhouse gas emissions continued, increasingly optimistic decarbonization scenarios were published, just because the adoption of the 2°C target pushed scientists to develop simulations capable of meeting it.

To achieve the 2° target, Integrated Assessment Models (IAM) require large scale CO2 removal : the 2° scenarios overshoot the temperature target before 2050, then "negative emissions technologies" would be used to draw the excess carbon back out of the atmosphere. The technology most widely invoked is "bioenergy with carbon capture and storage" (BECCS), which has only been tested experimentally, and poses various problems - above all, it would require an enormous proportion of the Earth's total arable land, competing with other priorities (food security, biodiversity…).

Meanwhile, between 2009 and 2015, the 1.5° target progressively gained momentum. Following the demand to “strengthen the long-term goal”, the Climate Convention created a "Structured Expert Dialogue" that submitted a report arguing that the 2° target would fail to save some populations and ecosystems, and that limiting global warming to below 2°C is “still feasible”. In the months before the Paris COP, the Climate Vulnerable Forum, with the help of scientific advisors from powerful foundations, lobbied politicians, civil society and the media, promoting the 1.5° target; and eventually succeeded in its goal.

Many climate scientists first expressed surprise (even sometimes indignation) at the inclusion of the 1.5°C target in the agreement, before resigning themselves, viewing it above all as a political compromise. However the emergence of the 1.5° target has triggered a heated debate in the climate community. It is not the goal in itself that is at stake, as both 2° and 1.5° require massive transformations of the economy. The difference lies in how they were adopted. The 2° threshold was constructed in a long process between science and politics and there was an official consensus around it, although internal debate existed. The 1.5° target, in contrast, obviously responded to a political demand. The tensions and difficulties which remained confined at 2° came to be expressed openly.

The debate on the 1.5° target took place in scientific journals (in the “opinion” pages), but alo in the internet and in the media. Scientists most directly involved are those who develop Integrated Models and produce socioeconomic scenarios known as "deep decarbonization pathways”; but debates also involve climatologists, specialists on the impacts of global warming, economists, social scientists, representatives of think tanks... At first glance, theses scientists seem to hold similar views : all consider that 1.5° of warming would be preferable than 2°, recognize the extreme difficulty of achieving this target and criticize the inadequacy of mitigation policies. However, beyong these common features, diverse perspectives are expressed. Some of them (the “optimistic”) emphasize the severity of the impacts of a 2° warming and the need to adopt a 1.5° goal. They focus above all on the “signal” that an ambitious target represents for politicians and industrialists, more than on its means of attainment. “Pessimistic" scientists, by contrast, view the long-term target as involving physical, economic, political, and social constraints. For them, the 1.5° goal, far from leveraging action, acts as a substitute for action, as “postulating large scale negative emission in the future leads to much less mitigation today”. Besides, in their view, these negative emissions are highly hypothetical and might have inacceptable social and environmental costs.

Thus disputes on 1.5° display a juxtaposition of different and heterogeneous justifications. While discussion on 2° was confined in a relatively limited community, debates on 1.5° involve broader groups with various interests. In order to set pathways for socioeconomic evolution, scientists working on Integrated Models choose the most cost-effective technology for the assigned target, regardless of their social or political feasibility. When other scientific communities get involved however, these choices become questionable : climatologists and economists criticize the simplistic character of the socio-economic scenarios and their implicit hypotheses, which neglect uncertainties and inertia, geographers examine consequences of BECCS technologies, political scientists question the relevance of a long-term temperature goal, economists are concerned with short-term transition toward decarbonization…

This discussion on 1.5° among climate scientists is even more lively since this target, although seen as inatteignable, is at the top of their research agenda. In December 2015 in Paris, the Climate Convention requested that the IPCC provide in 2018 a “Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways." The IPCC responded positively, as this kind of report is part of its functions. However it presents a challenge for the climate sciences community: the deadline is very tight; the report will be subjected to political examination; and many researchers are uncomfortable working on a 1.5°C target that they consider "a lost battle”. Nevertheless, as most of them want to stay in the game and to respond to environmental concerns, the challenge is thus to reframe the 1.5° target and transform the obligation to issue the report into an opportunity to perform interesting and novel research. Many research projects are created: some frame the 1.5° problem in term of uncertainty reduction, seeking to precise the remaining CO2 budget, or to find out whether a warming “threshold” exists for the collapse of the Greenland ice sheet, for example. For others, the Special Report will be an opportunity to study the impacts, not only of 1.5° of warming, but also of the economic and technological measures suggested to meet this target; or to explore the connections between climate change and other environmental, social, and economic problems. Thus, the 1.5° Report moves the debate back to the scientific arena and reframes it as an issue of scientific priorities and project funding.

The debate on the 1.5° target may be interpreted to reflect a change in the relationships between the science and politics of the climate. The paradigm shift in climate governance inevitably affected the science-politics relation that is at the heart of the framing of the climate problem. As scientists must produce a report on a target that they know to be unattainable, does this mean that the authority of the sciences is weakening ? The politicization of the climate problem may seem like a natural evolution: after a phase of alarm grounded in a consensual scientific diagnosis, the phase of economic and technological choices is necessarily more conflict-laden and political. Many climate experts indeed see a shift in the relation between science and politics: climate scientists should increasingly interact with policy makers, to highlight the risks, assess if the commitments are respected and work on « solutions ». Of course, that is not entirely new : scientists have been working on mitigation, adaptation or verification for many years; and peer-reviewed studies will continue to play an essential role in the future. However we can indeed observe evolutions in scientific practices and in science-policy relationships ; but above all, it is the discourse that changed. Discourses on a science « actionable » and « in service to society » are common nowadays, but climate change has been science-based since its beginnings, with IPCC playing a central role. Now it seems that the « science first » (or « linear model ») framing of the climate problem may be coming to an end. What will be a new framing, a new narrative or a new role for science in the climate regime is still unclear.

Meanwhile scientists face a challenge regarding their relation to policymakers : to clarify the issues at stake with the 1.5° Special Report and to highlight its contradictions and inconsistencies. The Report could offer the opportunity to acknowledge the inconvenient options for achieving the 1.5° target and to launch a critical discussion, among policy makers or a broader audience, on the risks of passing the 1.5° limit versus the risks of deploying carbon dioxyde removal on a enormous scale.

The Community of Integrating Assessment Modelling: overview, structuring and interactions with the IPCC expertise

Christophe Cassen[1*], Béatrice Cointe[2**], Alain Nadaï[1**]
[1]Centre International de Recherche sur l'Environnement-UMR8568 CNRS.
45bis avenue de la Belle Gabrielle 94736 Nogent-sur-Marne Cedex
[2]LAMES (Laboratoire Méditerranéen de Sociologie) – Aix-Marseille Université,
CNRS Maison Méditerranéenne des Sciences de l'Homme
5 rue du Château de l'Horloge 13094 Aix-en-Provence cedex 2
[*] *E-mail: cassen@centre-cired.fr*
[**] *E-mail: beatrice.cointe@univ-amu.fr*
[***] *E-mail: nadai@centre-cired.fr*

ABSTRACT

One year after COP21 in Paris that reached to a global agreement on climate action, it is timely to come back to the scientific expertise that is part of the debates about climate change. The almost symbiotic relationship between scientific expertise and political discussions in this field is well-documented (e.g. Shackley and Wynne, 1996; Agrawala, 1999; Miller, 2004; Edwards, 2010). This scientific expertise is not limited to climate science, but it is rarely considered in all its diversity, with physical and natural science drawing most of the attention. While the history and the role of climate scenarios/models and the development of expertise on climate change have been extensively analysed (e.g. Edwards, 1996, 2010; Guillemot, 2007; van der Sluijs et al., 1998), the development of socio- and techno-economic assessments in this field[1] has not received the same attention. However, these seem to play a crucial role in the elaboration of climate policy, insofar as they contribute to the understanding of the interactions between climate and societies. The rise of climate change on the public agenda since the late 1980s has prompted the need for quantitative assessments of the costs and impacts of mitigation strategies, in particular in view of the IPCC reports. To meet this demand, an increasing number of scenarios have been produced by Energy-Economy-Environment (E3) models. These gather different types of models – including the Integrated Assessment Models (IAMs) – which help to reduce the complexity and heterogeneity of relevant processes, inform and to an extent frame international climate negotiations, by producing a large array of numerical projections and scenarios.

This paper focuses on Integrated Assessment models (IAMs). It follows the co-evolution of the IAMs institutions and research community, and of their agenda of modelling efforts. We do so by focusing on the preparation of the 5th Intergovernmental Panel on Climate Change (IPCC) Assessment Report (AR5).

IAMs are stylized numerical approaches which aim at representing complex socio-physical interactions among energy, agriculture, the economic system… as systems. Based on a set of input assumptions, they produce quantified scenarios (e.g. energy system transitions, land use transitions, economic effects of mitigation, emissions trajectories…) that helps us exploring potential climate policy strategies. They are a heterogeneous category that has gradually emerged from a set of distinct intellectual traditions (Weyant et al., 1996; Crassous, 2009). IAMs can thus be built on rather different assumptions: they can follow distinct logics and represent the same processes with different levels of details.

IAMs and the scenarios they produce have grown central to the work of IPCC and seem to play an increasingly important part in climate negotiations and policies. Their influence has become particularly striking in the IPCC Fifth Assessment Report through the work and contribution of "Working Group III" – entitled 'mitigation of climate change'. During the process of preparing the AR5, Working Group III was chaired by one of the main actors of the current IAM research community. IAMs outcome and perspective were used as a guiding and structuring principle. IAM scenarios were expected to serve as bridging devices between the three IPCC working groups (which

[1] An exception is found is Hourcade (2007)

involve different scientific disciplines), albeit interviews suggest that the extent to which they succeeded in this respect remains unclear.

IAMs influence has built up conjointly with the structuring of IAM research as a distinct field of expertise and that of IAMs researchers network through a series of European Projects and regular meetings. All of this contributed to the consolidation of IAMs as a category of models with common – or at least comparable – characteristics. How did 'IAM' emerge as a relatively unified – though diverse – category and research field? How and where did the IAM community organise as such, and what is it made of? How have integrated assessment modellers organised the heterogeneity of their models so as to establish them as credible and reliable sources of policy-relevant expertise? How do they manage uncertainties, considering both the scope and complexity of the systems they study, and the many conceptual repertoires they draw from (physics, economics, systems dynamics, environmental sciences…)?

In order to answer such questions, we conducted a first series of interviews with modellers and key players in the IAMs community. These were undertaken on different occasions such as: the conference Our Common Future Under Climate Change (OCFCC) (Paris, July 2015), the venue to France of the head of the Energy Modelling Forum (October 2016), two visits to major research institutes in this field (PIK and PBL/University of Utrecht). These interviews have been completed by observations during two conference sessions focused on IAMs: a side event entitled « New frontiers of integrated assessment of climate change and policies » during the OCFCC Conference, and the 8th meeting of the Integrated Assessment Modelling Consortium (IAMC) (Postdam, November 2015). Attending and observing these sessions gave us an overview of the debates among modellers, the diversity of their approaches, the key challenges that are discussed in the community, the potential tensions within the community, and the way in which this research field is structuring itself. Last, we analysed the main inter-comparison modelling programs that were developed between the publications of the 4th and 5th IPCC reports and the material that was produced on these occasions (reports, articles…). In gathering and studying this empirical material, we tried to combine two approaches: a sociological perspective on the communities, networks, practices and discourses relevant to IAMs, and an historical perspective on the emergence and evolution of IAM research in terms of content, objectives and communities.

In our contribution, we will emphasize the role of the research programs that have been conducted in specific forums – such as: the Energy Modeling Forum coordinated by Stanford University, the EU FP7 projects…- looking at the way in which they contributed in setting the agenda of the modelling research community and in steering the production of scenarios. We will also analyse the mutual relationship between these program, their outcomes and the contribution of WG III to the IPCC process and outcome, in particular within the 5th Assessment report.

Model inter-comparison is a crucial part of these programs which have multiplied since the early 2000's. It consists in comparing the outputs of a range of models under similar hypotheses, usually focusing on one specific modelling and/or policy issue (e.g. technological innovation, land-use changes, etc.). Though it draws from similar practices in climate change research, the reliance on model inter-comparisons appears as a defining feature of IAM research, and it has played a role in the cohesion of IAM as a category of expertise relevant to climate policy.

For instance, since the 4th IPCC report published in 2007, the feasibility of low carbon trajectories consistent with the 2°C target that was institutionalized in 2009 at the Copenhagen conference has been a key question. It was the subject of the main modelling exercises conducted by the Energy Modeling Forum (EMF) headed by Stanford University and European research programs, mostly funded by the Commission. From 1991 onwards, the EMF organized a series of workshops dedicated to climate issues. In view of the IPCC 5th Assessment Report, EM 22, 24, 27 and 28 provided a global inter-comparison modeling exercise around the 2°C objective target, at different scales (world, US and EU level). Each of these sessions gathered researchers with an expertise of the question under consideration and followed the same protocol: a first stage was dedicated to the elaboration of a set of common scenarios based on harmonized assumptions that were then assessed by models. Since 2007, another large part of the scenarios produced for the IPCC 5th Assessment Report has come from similar inter-comparison modeling projects funded by the 7th European Framework Program[2]. This highlights EU's growing political and scientific interest in climate policies over this period[3].

The main findings of these research programs were synthetized in consolidated reports. They were published in international peer-reviewed journals in the energy and climate fields. The results from these projects represent a significant part of the scenario database included in the IPCC 5th Assessment Report , which included over 1000 scenarios.

The Integrated Assessment Modeling Consortium (IAMC), another and newer forum for discussing IAM research, also is a key arena for comparing IAMs and organizing priorities for future research. It was created in 2007 and was instrumental in the preparation of the contribution of Working Group III to the IPCC 5th Assessment Report. Besides providing resources and a setting for regular meetings of IAM researchers, IAMC puts a lot of efforts into the mapping and systematization of IAM models and scenarios, thereby contributing to their unification as a category of models.

Last but not least, we will also investigate how, by fostering common problem definitions and methodological approaches within the research programs or the creation of the IAMC, these inter-comparison modeling have contributed to delineate an IAM community. Our paper will wonder to what extent the IAM community can be described as an epistemic community (Haas, 1992) which participates, through the production of socio-economic scenarios, to the framing of the assessment of climate policies in IPCC Working Group III. It will also reflect on current evolutions, in particular those related to the Paris agreement on climate change and to the emergence of potential competing approaches and forums focused on national assessment and practical solutions in its wake (e.g Deep Decarbonization Pathway Project). In doing so, it will shed light on the epistemic, institutional and social dynamics involved in the production, framing and diffusion of a very specific type of expertise about the future.

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[2] It is more precisely referred here to the EUFP6 ADAM (http://www.adamproject.eu/), EUFP7AMPERE (http://ampereproject.eu/web/), EUFP7 LIMITS (http://www.feem-project.net/limits/) and to the RECIPE project https://www.pikpotsdam.de/recipe-groupspace/)

[3] After the US withdrawal of the Kyoto negotiations, the EU tries to play an exemplary leadership role in the climate negotiations (Gupta et al., 2000) and internally by adopting the EUETS (first carbon market) and ambitious climate objectives Europe (the EU 3*20 package, the Roadmap 2050 and the Frame 2030, that consist in a reduction of the emissions of -20%, -40% and -80% respectively in 2020, 2030 and 2050 (compared to 2005 levels).

SHORT BIOS

Christophe Cassen, is research engineer at CIRED and project manager in the IMACLIM modeling program. He has been involving in several EUFP7-H2020 and French research projects centered on the low carbon transition, and in international research networks (LCS-R net). His is interested in the analysis of path dependencies in international climate governance and in an historic perspective of the IAM community inside the IPCC group III on climate mitigation.

Béatrice Cointe, is an early-career researcher in Science and Technology Studies. She is interested in the interactions between politics, market dynamics and scientific and technological research round energy and environment issues. Her PhD thesis, written at CIRED, studied the deployment of photovoltaic technologies, markets and politics in France as driven by public support. She is currently a postdoc at Aix-Marseille University as part of a large interdisciplinary project on microbial bioenergy.

Alain Nadaï, is socio-economist and research director at CIRED, which is part of the French CNRS. His research activity has been centered on environmental controversies, environmental and landscape policies, and the energy transition. Applied field for his research work have been: climate change policy, EU pesticide regulation, EU product eco-labelling policies, landscape policies. He has been coordinating several research projects in the field of renewable energy (onshore and offshore wind power, solar PV) and low carbon technologies (Carbon Capture and Storage, smart grids) policies and development as well as sustainable energy communities and more recently on a sociological approach of modeling long term pathways. He has contributed as a leading author to the recent IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN) and is member of the French Athena Alliance dedicated to social Sciences.

Past floods and anticipating futures: Thailand and its post 2011 flood responses

Daniel Hogendoorn[1], Arjen Zegwaard[2]
[1]UCL, [2]UvA

This is a story about how we view the future of deltas, how such views become possible through networks of traveling knowledge, and the influence of shocks on such networks. In this case, we look at two departments governing Bangkok, and at two shocks, a 2011 flood and a 2014 *coup d'état.* But we start by discussing deltas.

The delta multiple

Deltas across the world are increasingly researched. Such research is often justified by saying deltas are victims of climate change, and focal points of population and economic growth. Such research then, informs long term planning. While we research deltas too, we shift emphasis, even though we think it will bear on planning. In this abstract, we discuss one delta, the Thai Chao Phraya delta, home to Bangkok. This sinking delta too faces drought and floods, and rapid urbanization. In its brief history, Bangkok and its surroundings transformed from a sparsely populated region where people had no roads but travelled through the Chao Phraya river and a dense system of canals, to a global megacity filled with highways and skyscrapers. The speed of development arguably has contributed to many local problems, and it has added dimensions to a delta that is increasingly complex.

When we use the label of a delta, it is a category we employ for river-mouths branching to the sea. But increasingly, when we speak of deltas, we think of them as complex loci of many separate developments. While the developments in the delta are of a brute and material nature, their becoming is too a result of how people who deal with local problems view and describe *their* delta. For example, if we examine flooding in the city, the delta is shaped by many different views. One actor, say, makes the proximate problems of drainage prominent, based on immediately anticipated rainfall from radar stations. And another takes up our mental space on the basis of descriptions that link to anticipated climate change, city networks and regional climate models.

This raises the question of how such views on the delta arise. Certainly, depictions of what the delta 'is' have changed since the earliest Siamese history, and since merchants traded using maps to navigate the waters in this never colonized country. How, and through which networks – are these contemporary visions on the becoming multiple that is the complex delta made possible? From where and how do descriptors of the delta travel to become signals, forming this view on what may be anticipated? What can we learn from Thailand about the becoming of deltas?

First, we want to highlight two examples of flood management in Bangkok, and show how their expectation of futures is made possible by separate networks allowing what we call the back-and-forth travel of knowledge. Second, we want to discuss Thailand, since it is an extreme and 'tidy' case in showing how regularities at a larger scale can form and disband the networks of traveling knowledge. That is, regularities that indiscriminately impact all networks of travel. We focus on the shock of the 2011 flood and the 2014 *coup d'état.* Thailand is an intriguing case, as its floods and political upheavals have so frequently caused upsets. In Thailand, both flooding (of desirable and an undesirable kinds) and *coup d'états* occur regularly enough, and impact all actors governing the delta. Since 1932, with 19 coups (12 effective) and 20 different constitutions and charters, Thailand holds a world record.

Fractured visions. Two departments in Bangkok

In this abstract, we highlight two separate departments of the Bangkok Metropolitan Administration (BMA), Bangkok's most influential office, that responded to the floods of 2011.[1] Each of the BMA departments forms different networks in Thailand and across the globe. Each uses, too, different apparatuses of techniques, tools and concepts, some of which travelled through global networks. These apparatuses make certain expectations come into view, and favor specific inferences. Such is to be expected from the idea that different departments justify their existence from handling one task, and not another. It also means that the delta, in its becoming, is reshaped by these performed, multiple and fractured visions.

In the BMA, one department, the Department of Draining and Sewerage (DDS), deals with anticipating the immediate stress of the the tropical rain, and the Chao Phraya River and many canals that run through Bangkok. For the DDS, the delta is ad hoc and close by. It brings close this world through knowledge fetched from afar. It uses, for example, radar-systems that come from the U.S., and works from an emergency room in the style that can also be observed in, say Texas (Hogendoorn, forthcoming), be it that the bulk of the coordination is done with walkie-talkies instead of smartphones (a surprise, since the rest of Bangkok uses smartphones for everything). The radars translate their measurements into virtual depictions of red and blue dots moving over a green Chao Phraya delta, simulating rain clouds on the screen in front of them. The people in the room infer from the moving dots where the rain clouds will be in a couple of hours, and which parts of Bangkok will need assistance to cope with rainfall and drainage flooding. They do so by taking landline calls and using walkie-talkies. When we were there, the people of the DDS were negotiating with a Danish research institute, hoping to sell a model that would allow real-time flood forecasting. In this manner, the complete view of the delta can be tied to different actors operating across the globe. Even if the drainage department acts 'local', it can only do so via extensive networks across the globe. Its vision of the future is rooted in drainage systems, sensors and radars from the US and the feedback at a city-wide set of sluices and pumps imported from Japan. The BMA anticipates in hours, days at most. Its floods are made by rain, not by the river, let alone by events somewhere else in the climate or more distant social system. Even the cities and industries upstream, who certainly influence the water-levels in Bangkok are mostly outside the view of this department, although the Governor of the BMA does consult with the deputy minister and the more rurally oriented Royal Irrigation Department (Interview Royal Irrigation Department).

The other department deals with the resilience of the city. It ties directly to the Governor of Bangkok, whose representative offers advice to the Governors office. This department views the delta at a different spatial and temporal scale. For the resilience-officer, the future is more distant and ephemeral. The delta is the entire basin in Thailand, not just the Bangkok metropole. And it is wider still, as the delta becomes interconnected in used representations to the global climate system, while Bangkok becomes part of an order of city-networks that the resilience-officer himself takes part in. The department envisions with the aid of quantitative measures, say counting car-ownership to infer future population growth. Or crafting scenarios on uncertain climate change. Or through reaching a shared interpretation arising from recurrent talks with resilience-officers from other mega-cities. These officers congregate once a year, as part of the 100 resilient cities alliance, funded by the U.S. Rockefeller foundation. The Bangkok department has formed a clique with some likeminded cities in Australia and New Zealand, and works more closely together to share approaches and benchmarks. The department does not do climate-research itself. It has to rely on reports made by others, such as the summaries crafted by the IPCC on the state of the climate. Or it enlists the work of universities using various types of regional climate models that downscale global circulation models. Yet, the resilience-office also ties in well with the local philosophy of the King that passed away. This philosophy, is called the sufficiency economy, and roughly maps on to ideas of sustainable growth and prudential living. This local resilience effort is tied to a post-national cosmopolitan effort, contributing to a globalized set of delta descriptors.

[1] Our research program studies the acquisition, or 'travel', of knowledge that comes to shape visions on the Chao Phraya and Ayeryawaddy deltas. The aim of our research is to offer a comprehensive view of different views on the Thai delta. This paper is meant to test an idea. We are early on in our research, and thus welcome feedback on the idea.

Two shocks, a flood and a coup

In 2011, Thailand's Chao Phraya delta, location of Bangkok, experienced an unexpected and intense flood, causing 815 deaths and over 45 billion U.S. dollars of damage (Interview BMA). As it goes with disasters, the stress mobilized many, in government and outside, in Thailand and abroad.[2] In our wider research, we examine this mobilization, and how it drew in the networks that allowed different envisioning of the deltas in the manner described. For example, Australians came to Thai aid, and the Thai government announced a multibillion dollar budget for flood management plans just after the flood. Many actors such as engineering companies from different nations in the world rushed in, hoping to win contracts in the planning effort. Tenders were won by Japanese and Korean actors, plans took shape, and contracts for mega-projects were set up. In the Chao Phraya, these actors encountered many Thai actors, with different yet overlapping tasks and little coordination among them. An important role there, too, was for the Thai King, who passed away during our field work, and was a patron of water-management (involved, for example, in the retention-areas called 'monkey cheeks' and the elevated highways acting as dykes around Bangkok). The two departments of the BMA too enrolled in many networks. The resilience office was largely motivated as a result of the 2011 flood, joining the resilience alliance after it arose. The 2011 floods placed the climate and resilience of the city on the map. For the Department of Draining and Sewerage, the floods pointed out the many points where governing was weak and needed improvement. Projects were started, including the planning of massive drainage tunnels.

In October 2016, the Governor of Bangkok, head of the BMA, was ousted on corruption charges brought up after the *coup d'état* from 2014. When the *coup* occurred, at a stroke, most plans associated with the government were put on hold. Coalitions disbanded. Visions of the future delta, so artfully recombined, faded from view again. This held for the large scale plans to make the Chao Phraya and Bangkok safer. For example, Dutch civil engineering companies who had hoped to sell their plans, attended elsewhere with hopes taken away. K-Water, a Korean company, had wooed the ousted government to win a big Tender, and so its plans became suspect too. Yet, it also held for the BMA's departments. We are currently mapping how these events affected the departments. Most plans that did find their way towards implementation seem to have involved the King's personal attachment (and money).

Conclusion

The Thai delta is characterized by fractured governance and fractured visions. Such visions obviously relate to the separate tasks an actor sets out to do, anticipating a favorable outcome. With such disparate actions, what a delta is too becomes more of a multiple, more complex strands continuously coming into being and interacting. It goes beyond this case to describe the considerably fractured governing of the Chao Phraya. But the idea we are trying to flesh out, is that within fractured governing, large scale shocks like floods and political upsets, make for arrangements and disbanding of the networks that allow traveling knowledge to enter and cease entering – the formation of signals allowing novel inferences on the future delta. Good foresight, then, requires too to have a view on how multiple visions are, and how such visions depend in part on large upheavals. These upheavals, via networks, come to shape views on the delta, and in the end the delta itself.

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[2] Examples are easy to find. The Dutch Delta plan after the 1953 flooding disaster had hit the Netherlands. The responses to the 2005 flood in New Orleans. Superstorm Sandy hitting New York in 2012. Texan efforts after hurricane Ike (Hogendoorn, forthcoming).

SESSION 2 : Dealing with uncertainties in megaprojects

Chair: Jean-Alain Héraud

Opening up of megaproject appraisal – challenges of high-level radioactive waste management as an area of (a)typical type of megaprojects

Markku Lehtonen*
Groupe de Sociologie Pragmatique et Réflexive (GSPR), Ecole des Hautes Etudes en Sciences Sociales (EHESS), Paris, France
&
Centre CONNECT, ESSEC Business School, Cergy-Pontoise, France
* *E-mail: lehtonen@essec.edu*

INTRODUCTION

Megaproject evaluation has hitherto largely adopted a linear-rationalist perspective to explain the frequent failure of megaprojects to meet the 'iron triangle' criteria of project performance: delivering on time, within budget, and according to specifications [1]. It interprets the chronic failure of megaprojects to reach their objectives as a result of project selection dynamics, which would favour the "survival of the unfittest", i.e. the selection and financing of the least viable projects [2, 3]. The main reasons would be the inherent optimism of human beings ("optimism bias", or "planning fallacy") [2], and above all, "strategic misrepresentation" [2, 3], or "malevolent design" [4]. This latter explanation sees project approval decisions as guided by strategic, rent-seeking behaviour by planners and other key actors, who would misrepresent the costs and benefits in such a way as to maximise the project's chances of winning public funding [5-7]. The very long timeframes accentuate the problems further, because often project advocates – including politicians – would no longer be in office when the project's actual viability could be assessed reliably [8]. In consequence, the advocates of this perspective call for greater accountability, *ex ante* control, and more effective *ex post* monitoring and enforcement (e.g. benchmarking, peer review, media scrutiny, financial rewards, and sanctions) designed to minimise strategic, self-interested behaviour [8].

OPENING UP OF MEGAPROJECT EVALUATION

Alternative readings of megaproject governance and evaluation interpret megaproject governance in the light of the multiple alternative rationalities governing the behaviour of policy actors. These interpretations emphasise the constantly evolving nature of megaproject goals and objectives; they reject the idea of malevolence as the dominant explanation for megaproject 'pathologies'; they reject the rational actor model in favour of a view acknowledging the diversity of rationalities underlying human behaviour; they stress learning, reflexivity, complexity and dynamism of megaprojects; and they advocate an 'opening up' of appraisal and decision-making to a broad variety of perspectives and stakeholders. These interpretations also call into question the notion that megaprojects would represent clearly definable projects, and characterise them instead as fluid and open systems, with constantly changing boundaries – "programmes of projects" [1] or *"networks of people and organizations that work more or less coherently and purposefully to address complex public problems"* [9].

Applying to megaprojects the principles of "network governance", arguably suitable for solving complex, unstructured problems that require cooperation between a diverse range of actors [9, 10], the advocates of these alternative approaches view uncertainty not merely as a problem, but also and above all as an opportunity to foster voluntary, horizontal, reflexive and adaptive governance and coordination among interdependent actors [11], involving the exploration of alternative pathways [12]. Decision-making would entail not only rational choice among a set of known options, but also the redefinition of the range of the available options [13, 14]. Given constant technological change, shifting societal preferences and changing power relations, decision-making under uncertainty highlights a dilemma typical of technological choices such as those involved in the long-term management of high-level radioactive waste (HLW): to obtain information about its consequences, a technology first needs to be implemented, yet with implementation the technology also gains its own inertia and escapes the control by policy actors [15].

THE TWO DIMENSIONS OF 'THE SOCIO-ECONOMIC'

Drawing on lessons from megaprojects from various sectors [16], this paper explores the case for and the challenges faced by two strategies of improving megaproject evaluation, in line with the above-described notions of network governance and 'positive uncertainties': 1) going beyond the dominant linear-rationalist notion of policy processes, and stressing the objective of opening up appraisal processes in order to enhance learning and reflexivity; and 2) extending the evaluative criteria beyond the 'iron triangle', to cover the various socioeconomic impacts and preconditions for project success. The first strategy would entail embracing the multiplicity of interpretations of policy processes and rationalities motivating human behaviour – an approach that would highlight, take seriously, and embrace uncertainties. The second strategy refers to the socioeconomic aspects as performance criteria in project evaluation, including both socioeconomic impacts and the socioeconomic preconditions for successful project implementation. Arguably, the 'iron triangle' considerations constitute only some of the multiple criteria against which the performance of megaprojects should be evaluated, and neglect notably their implementation processes, and the 'subjective' dimensions of 'the social'.[1]

SPECIFIC CHARACTERISTICS OF HIGH-LEVEL RADIOACTIVE WASTE MANAGEMENT

The paper highlights the specificity of HLW management projects, which drive certain megaproject characteristics to their extreme, while being rather atypical megaprojects in other respects. The extremely long timescales involved represents an example of the former: while megaprojects usually entail long timeframes, they seldom raise intergenerational justice issues of such acuteness as HLW management. In particular because of the dominance of safety as the overriding concern, the state plays perhaps an even greater role in HLW management than in megaprojects in other areas. Furthermore, the ultimate *raison d'être* of HLW management makes these projects atypical: unlike 'normal' megaprojects, which seek to provide added benefits to the society, in the form of economic development, job creation, etc., HLW projects respond to the imperative of solving an existing 'societal problem'. Delivering on time and within budget remains important, but secondary to safety as the dominant performance criterion. A conventional cost-benefit analysis (CBA) then appears as inappropriate, because the society has no true choice – the waste problem needs a solution, hence the 'benefit' side in the cost-benefit equation entails in fact a legal obligation. Instead of calculating the value of this benefit, we could instead take it as a given, whereas calculating the cost would require a stepwise learning process, to accommodate the multiple uncertainties relating to many of the input parameters. Apart from the uncertainties concerning alternative disposal methods, uncertainties also concern general political choices: waste management solutions are significantly shaped by decisions such as whether or not to continue the use of nuclear power or reprocessing of spent nuclear fuel.

OPENING UP MEGAPROJECT EVALUATION TO A BROADER SET OF PERFORMANCE CRITERIA

From the perspective of the second type of 'opening up' advocated here – going beyond the "iron triangle" of project performance criteria – a key challenge consists of abandoning the dominant approach that evaluates the social dimension of megaprojects merely in terms of the objective, the measurable, employing methods such as 'social impact monitoring', often reduced to a 'checklist approach'. Such approaches are weak at fostering learning, they tend to disempower and objectify people, while reinforcing the existing power asymmetries and failing to involve local communities [18]. Furthermore, when the social dimension is addressed under the notion 'socioeconomic', evaluation typically emphasises 'the economic' [19], and largely neglects aspects such as culture; ethics; subjective wellbeing; personal and property rights; people's fears, aspirations and identities [19]; as well as the relationships between society and nature [20].

[1] The 'subjective' denotes here the symbolic representations and meanings attributed to phenomena by social actors, and changes in society as experienced and perceived by the actors involved, whereas the 'objective' aspects can be measured through indicators such as employment rate, demographic trends, or literacy rate [17].

Also from this perspective, HLW management presents particular challenges. As megaprojects that seek to achieve a local solution to a national – in fact, even global – problem, HLW management projects raise to the fore issues of justice, such as those concerning the respective roles and duties of 1) the state as guardian of the general interest and 2) the sub-national actors that are often torn between their responsibilities towards the state and towards their local constituencies. Two questions stand out. First, to what extent can local communities be held responsible for solving a national problem? Second, what right does the state have to impose upon a community a solution deemed to be in the interest of the nation, even in the interest of the humankind? The promise of the various local socioeconomic benefits from the projects – and the economic support measures and 'community benefit packages' – complicate matters further, not least when the project is planned and implemented in an economically less developed area [21]. 'Benefit packages' often generate contrasting reactions at the local level, some actors welcoming them as an indispensable source of development, while others condemning this kind of support as an act of bribery [22].

CONCLUSIONS

The paper concludes by highlighting a number of key challenges and dilemmas that need to be resolved when seeking to open up socioeconomic evaluation of HLW management. Four issues stand out in particular:

- How to balance between two objectives: keeping the options open to retain the capacity of adapt to evolving situations, and maintaining sufficient control over the system through the reduction of complexity, closing down decisions, and establishing clear lines of accountability? Are the 'stepwise' and reversible implementation strategies adopted by many countries in nuclear waste management adequate responses in line with Collingridge's [15] advocacy for incrementalism and retaining "an exit strategy"?
- Given the current overemphasis in megaproject evaluation on accountability as its key objective, greater attention to learning is needed. To combine the often mutually conflicting objectives of learning and accountability [23, 24], accountability needs to be redefined, drawing on the ideas of network governance [11, 25].
- In megaproject evaluation, there is an inherent tension between the objectives of 'opening up' and 'getting things done' – between an 'external' and an 'internal' approach. For instance, Social Impact Assessment as a method of 'managing social issues' clearly adopts an internal approach, in seeking to ensure that the project in question gets done, albeit in the socially least obtrusive – or indeed most favourable – manner. Opening up would, by contrast, imply stepping 'outside of the system', and evaluation would then explore not only the impacts of a project, but also the problem framing and the *raison d'être* of the project, as well as "our convenient assumptions" underpinning the evaluation methods and defining what is meant by being 'operational' and providing 'actionable' knowledge for decision-making.
- Keeping things open cannot carry on forever, but decisions have to be made, sooner or later. But how does one know when a situation is 'ripe' for closing down – choosing a single consensual waste management option, for example? By whom and through which processes should the decision of closure be made? Is a 'fair and inclusive process' a sufficient precondition to a decision to close down? Does closing down a technology choice also imply closing down the knowledge and problem framings?

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How stakeholder and citizen participation influences evaluation criteria for megaprojects: The case of the Belgian LILW repository

Anne Bergmans, Environment and Society, Faculty of Social Sciences, University of Antwerp, Antwerp, Belgium
anne.bergmans@uantwerpen.be

In this paper we elaborate on the siting process for short-lived, low- and intermediate-level radioactive waste (LILW) in Belgium as a case in which the criteria for an *ex ante* evaluation of the project have been – and continue to be – constructed throughout the assessment and decision-making process. We investigate whether indeed wider citizen participation improves the evaluation of the socioeconomic impacts and leads to a more sustainable conception of the project.

After a clear failure to site a LILW repository facility in a top-down manner with the idea to achieve the optimum scenario from a national and techno-economic perspective, the Belgium radioactive waste management agency, ONDRAF-NIRAS, resorted to a co-productionist and more bottom-up and voluntary approach. All existing nuclear communities, and any other interested municipality, were invited to participate 'in partnership' in a technical and social feasibility study before deciding to volunteer as a candidate host site or not. Participatory processes were organised at the municipal level, by means of a platform named 'Local Partnership'. Within this platform, local actors (including civil society organisations, politicians, socioeconomic actors and individual citizens) were involved in designing the repository and in setting the conditions under which their community would be willing to host the repository facility as part of an integrated project (Bergmans et al. 2006, Bergmans 2008). The partnership programme started late 1999, culminating after 5 years of study and debate in two candidate sites with their respective project blueprints, one of which was chosen by Federal Government decision in 2006. However, siting did not prove to be the end of the process. Participation (through two Partnership structures – STORA and MONA - in the neighbouring communities of Dessel and Mol) continued during the more detailed elaboration of the various components (see figure 1) of the proposed project, later baptised the cAt project.

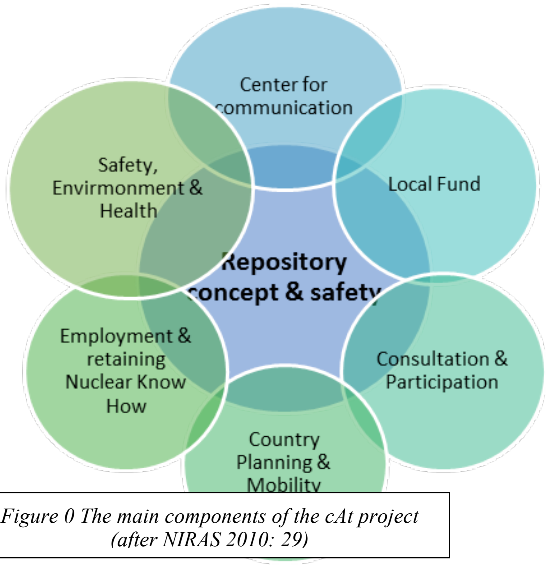

Figure 0 The main components of the cAt project (after NIRAS 2010: 29)

Characteristic of the cAt project as a megaproject, is that it involves a multitude of concerned parties and that the project continues to evolve, leading to some difficulty in making concrete long term budget estimates. To deal with this, project governance was widened by incorporating local community representatives into the project management structure. As a consequence, the classical inside and outside distinction of the project management became more fluid and ambiguous, and the distinction between project "governing" and project "governance" (Sanderson 2012) less explicit.

In our analysis of this particular case, the focus has been on megaproject management: not on 'what goes wrong', but on 'what goes on'. We have looked at what impact – if any – a widening of the notion of project management may have on project culture, on managing uncertainty and on assessing performance at different stages in the project's development.

Decision-making as a process of 'satisficing'

It is our understanding that the enlarged project management structure of the cAt project and the way it operates could be seen as an example of what van Marrewijk et al. (2008) describe as the "*ambiguous culture and bounded rationality*" of megaprojects. Like them, we did not find evidence of a systematic and deliberate underestimation of costs; but rather a situation that is *"managed to the best of their abilities, by professionals and civil servants in the context of very complex operations,* *paradoxes, uncertainties and ambiguities which surround these projects"* (van Marrewijk et al. 2008: 597).

'Iron triangle thinking' with its crude criteria of "*on time, on budget and within prescribed specifications*" (OMEGA 2012: 2) does not seem to dominate the project culture in this particular case, nor did we see any evidence of outsider pressure in this regard, at least at the current stage in the project development. A strong focus on project content (a safe repository concept within a broader project answering to the conditions set by the host community) and a relatively relaxed attitude towards project timing by most partners, created space for reflection and negotiation. There is no doubt this has led in some instances to additional uncertainty, agitation among certain partners and even unnecessary stalling of decisions. However, it is our understanding that the inclusion of local community representatives in the project management, an overall absence of excessive pressure and an emphasis on taking time to resolve disputes among key partners, has contributed to a feeling of trust in the process and to a mutual feeling of collaboration within the project, for the benefit of the local community.

Our case suggests a need to complement the notion of bounded rationality with that of multiple rationalities. The latter is often depicted as part of the former (e.g. Atkinson et al. 2006, Sanderson 2012). However, our case illustrates that they both play a role, but in different ways. The more complex the project and the more actors involved, the greater the tendency of these two types of rationality to reinforce each other. While the ONDRAF-NIRAS project team is central in the coordination of conceptual design, project planning and development, it could not be regarded as the "*single centre of calculation and control*" (van Marrewijk et al. 2008: 592). Partnership members take part in monthly project meetings, in which they systematically discuss planning and the state of affairs of the different components, while decision-making at the project level is shared between ONDRAF-NIRAS and both Partnerships in the form of a Steering Committee.

This allowed for the incorporation of emerging project goals along the way. For instance, Partnerships where created when it was necessary to give a role to host communities; informing the public by means of a communications centre and long-term participation became a key feature of the project; and the implementer negotiated an inspection gallery with the regulator on behalf of its local project partners. Even after the main boundaries for the project were set in 2006 (a surface repository in Dessel, as part of an integrated project that meets local requirements) and a Masterplan consolidated in 2010, new insights have prompted numerous smaller adaptations (e.g. changes to the original design of the repository; creation of an additional funding mechanism to cover the cost of project components of a socio-economic nature).

The more inclusive the structure of project management, the more ambiguous is the project culture – or the more diverse are the project cultures – shaping the project's development. However, even the most inclusive project management will always be confronted with an outside reality, again with different rationalities, perceptions and interests. Flexibility to deal with that type of uncertainty and the ability to deal with changes in stakeholder 'morphology' over time are thus important.

Indeed, throughout the various stages of the development of the cAt project, project management has taken different forms. Initially foreseen to last for about two years (the estimated time to conduct feasibility studies), the Partnerships have been in place for over 15 years. During this period, their role and relationship with the implementer – but also with other actors, such as the regulator, the municipal council, and the other Partnership – has changed and adapted according to the project management stage. This flexibility, learning and adaptation appear to be more present, though in a more incremental way, as the project develops and becomes more complex.

Managing uncertainty through flexibility

It therefore seems appropriate to conclude that uncertainty management in this project entails flexibility as well as tolerance to a certain level of vagueness and complexity, rather than attempts to reduce uncertainty at all costs. Uncertainty management in relation to the financing of the whole project is of particular interest here, because it demonstrates how retaining a certain level of vagueness and complexity could prove to be key to guaranteeing the necessary funding will be available. In order to overcome a possible legal dispute on whether the legal status of the existing funding mechanism for the repository project would entitle it to be applicable to all aspects of the integrated project, a second funding mechanism was created to cover for the socio-economic components. By indicating certain project components to be financed through both funds without defining exactly how costs will be divided between the two, some room was created for eventually dedicating costs to a particular funding structure.

In spite of its relatively long history the cAt project is technically still in a planning phase, as no licence has yet been obtained for its central component. Nevertheless, some components are already being launched (e.g. the governing body for the Local Fund will be put in place in June 2016), thus making the transition from plan to project more fluid. In spite of Masterplans and detailed technical licence applications, many project components remain relatively open and difficult to describe in tangible and measurable outcome criteria. This continuous project evolution resonates well with the view of a (mega)project being "*the constantly renegotiated sum of the activities of the individuals involved*" (Hällgren & Söderhol, in Sanderson 2012: 441). The cAt project clearly is not a pre-defined object, but one that is "*continuously constituted and reconstituted through the socially situated activities of all of the practitioners involved, however tangentially*" (Sanderson 2012: 441).

Therefore, a continuous process of (re)assessment, particularly regarding the socioeconomic impacts of the project, appears to have unfolded, guided by mainly qualitative performance criteria. These criteria remain rather vague, thus allowing them to act as boundary concepts or boundary objects (Star 1988, Star & Griesemer 1989). In our case, we could distinguish safety, local acceptability, a willingness to adapt and flexible financing mechanisms as important performance criteria. Rather than quantifying these criteria or specifying in all cases how to meet them, it was the Partnership's merit to introduce them, to make space for them and to keep open – or to reopen – negotiations, if it felt that its criteria were not being met and the proposed alternative was not considered satisfactory. We consider this as a clear example of bringing in 'the socio-economic' through performance criteria – or at the very least through a change in approaching performance criteria in a qualitative, rather than a quantitative way. In time, this might lead to more specifically defined performance criteria. However, even if that stage is not reached, meaning and appreciation can be attributed and qualitative assessments made on the basis of 'overlapping interpretations'. As Fox (2011: 82) puts it, these performance criteria as boundary objects thus become active *"elements that encapsulate the broader social meaning of a concept, theory, technology or practice, and the underlying relations that surround its development and adaption"*.

Conclusion

Our case shows that complexity should not necessarily be seen as a negative attribute. Projects of this magnitude are characterised by a variety of project cultures and understandings, both within and around its management structure. Acknowledging complexity creates room for negotiation and a more conscious way of approaching megaprojects as being continuously (re)constituted through the actions of all concerned parties, within a context of multiple bounded rationalities leading to socialised forms of often irreducible uncertainty.

The absence of a preconceived idea of what the project or its management structure should look like at the outset, contributed to the robustness of the project governance. It is hard to predict whether or not the project, when fully implemented, will effectively be judged as sustainable. However, it appears to us that a flexible and inclusive management culture and a certain vagueness resulting from the application of mainly qualitative performance criteria has been constructive in managing and handling uncertainty in this particular case.

Further research is obviously needed, but we would suggest that in megaproject assessment, the time is nigh for replacing the Iron Triangle considerations by a *'Velvet Triangle'* thinking in terms of adopting an open and flexible project culture, fostering multiple rationalities through qualitative performance criteria, and managing uncertainty through tolerating vagueness and complexity.

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Financing a million years?
The case of the North-American Nuclear Waste Program

Author Name(s):
Başak Saraç-Lesavre, Centre de Sociologie de l'Innovation,
Mines Paristech, PSL Research University,
Paris, France.
basak.sarac-lesavre@mines-paristech.fr

Yucca Mountain (Nye County, Nevada) was legally designated as the United States' repository for high-level radioactive waste and spent nuclear fuel in 2002. To keep alive the memory of the site, should a universal language be invented, or should we construct a new permanent marker, or a monument, that would last essentially forever? Or might reproductions of The Scream by Edvard Munch be useful as icons that would universally communicate to distant futures the horrors that could result from digging up nuclear waste from its geological resting place? A number of experts have been attempting to answer these questions in an extremely serious manner (Galison and Moss 2015). This is one form that the concern about the long-term future of nuclear waste (and of society) can take. Another one, perhaps less technologically sophisticated, but nevertheless crucial, is to ensure that such a large-scale and long-term programme would be financed in a durable and accountable manner, which requires the reconciliation of different temporalities (the present value of a future benefit). Such reconciliation relies on the use of a contested economic convention: discount rate. The paper concentrates on the uses of this convention in the U.S. nuclear waste programme.

It takes thousands of years for the radioactivity of the nuclear waste produced by nuclear power plants to decline and reach tolerable levels (i.e., the natural radioactivity level of the original ore used to make the fuel). Containing nuclear waste has been a prime concern for scientists and administrators in the nuclear milieu for decades; when national nuclear waste programmes were conceived, disposing of waste in deep geological repositories was considered the most efficient means to surely and securely do so (e.g. Sundqvist 2002; Macfarlane 2003; Bloomfield and Vurdubakis 2005; Barthe 2006; Walker 2009). This means separating nuclear waste from everything else (society and the environment altogether) for as long as possible, ideally forever—even though hiding something is obviously not the same as making it disappear (Hetherington 2004). But it also means aligning the physical temporality of the radioactive material and of the geological site with the organizational temporality of the repository project: from its construction to its closure and then far beyond. In 2008, before it was abandoned, the operational lifetime of the Yucca Mountain repository project was estimated to be around 120 years.

In the United States, the first regulation for licensing a repository project demanded that the repository ensured safety for surrounding areas for about 10,000 years, the same timeframe for which the geological repository for military nuclear waste, Waste Isolation Pilot Plant or WIPP, currently in operation in Carlsbad, New Mexico, for example, must demonstrate compliance with regulatory safety requirements. In the Yucca Mountain case, on advice from the National Academy of Sciences, and as directed by a court order, that timeframe was extended to 1 million years (e.g. Shrader-Frechette 2005). Social scientists have been intrigued by the attempts of contemporary institutions to control and master distant futures. Some studied decision-making processes associated with the selection of techno-scientific options for the governance of nuclear waste (e.g. Callon et al. 2001; Barthe 2006), and more broadly, of risks and uncertainties (e.g. Joly 2001; Stirling 2008), while others have examined procedures applied to the selection of disposal or storage sites (e.g. Simmons and Bickerstaff 2006; Blowers and Sundqvist 2010; Lehtonen 2010; Bergmans et al. 2015), evaluated risk perception or "acceptance" levels among citizens on such sites (e.g. Kasperson et al. 1988; Jenkins-Smith and Bassett 1994; Jenkins-Smith et al. 2011), or shown how techno-scientific knowledge is stretched in an attempt to govern distant futures (e.g. Oreskes 2000; Metlay 2000; MacFarlane 2003; Bloomfield and Vurdubakis 2005).

The existing literature on the exceptional temporal schemes associated with nuclear waste seldom directly refers to economic mechanisms, which are thus generally taken for granted, as are instruments that support the accomplishment of the highly sophisticated, extremely long-term public policies. Yet, public policies on topics such as nuclear waste management are implemented through the deployment of a diverse range of tools, including economic ones. The investigation of those tools – their displacements, and their configurations – offers a novel account of national nuclear waste policies in the making. Furthermore, these tools serve as mediators in processes whereby the moral, technical and political aspects of public policies are negotiated and reconfigured.

To undertake such an exploration, the paper takes a different empirical angle and proposes tracing the efforts of contemporary governmental institutions to answer a simple, modest and low-profile question: does the project fit within the budget? Or, in other words: are sufficient funds collected in order to finance a specific nuclear waste programme? Evaluations seeking to answer these questions are concerned with assessing whether the megaproject meets the 'iron triangle' criteria of project success, i.e. cost, budget, and predefined project specifications. Megaprojects frequently exceed their budgets and timetables. The common way to approach this is to strengthen efforts to enhance control, transparency and accountability in such projects. This often leads to the proliferation of publicly available yet often rather technical evaluation reports that assess the viability of megaprojects. One way to approach those evaluation reports is to consider them as rationalistic approaches to the governance of megaprojects by concentrating on the motives driving their production. What this paper proposes instead is to treat these evaluation reports as an extremely rich resource for empirical investigation. By paying attention to the financial evaluations that are conducted throughout the implementation of a very long-term public policy, it suggests observing the dynamic and evolving role that the 'State' adopted throughout the process, and the expectations about the future states of society that thereby became material.

The paper points out how, through the uses of discount rates, 'State' can adopt various alternative self-definitions: it can act as a 'private investor', 'a consumer', 'a public investor', and its actions can enact future states of 'the society' or 'the economy' in multiple ways – as catastrophic, prosperous, stable or stagnant. Political and moral choices configured and reconfigured in the uses of such a convention can be rendered visible, making institutions and their choices accountable to large audiences and opening them up to questioning. Those choices can also be delegated to the instances of technical expertise, protecting them against criticism and closing them down to public debate. The paper argues that opening up the uses of economic conventions to public debate would be an important step towards democratising the government of techno-sciences.

Inquiring into the ways in which the notion of 'polluter pays' is translated into practice, the paper also shows how margins of such a responsibility are negotiated. Should any problem occur beyond the licencing period of the programme, its financial consequences were to be transferred to the 'State'. This generated the expectation that the financial responsibility for a material that would remain radioactive for thousands of years could be contained inside a fee calculated for each kWh consumed. I argue that, such a definition, on the one hand, reflects the individualisation of responsibility, while on the other hand, attributes 'State' the role of an eternal guarantor that both attempts to protect future generations from the consequences of modernity, and seeks to prevent nuclear industry to be burdened from its negative externality. In the terms of Emilie Hache, leaving us with a tension between neoliberal and pastoral ideas of responsibility (Hache 2007a, 2007b; Foucault 2008).

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Başak Saraç-Lesavre completed her PhD degree at the Centre for the Sociology of Innovation (CSI), Ecole Nationale Supérieure des Mines de Paris. Concentrating on the U.S. nuclear waste programme, she explored the attempts of contemporary institutions to govern long-term futures, and showed the struggles they face to reach a balance between accountability and durability. She currently holds a post-doctoral fellowship at the CSI and explores the current European efforts to harmonize nuclear safety, particularly in the post-Fukushima context.

Uncertainties and opportunities in megaprojects planning, assessment and decision-making process

Geneviève Zembri-Mary
University of Cergy-Pontoise–MRTE

Megaprojects planning process and decision-making process can meet uncertainties. The megaprojects can be transport infrastructures, development projects, nuclear plant, and so on. They are very expensive. They can have impacts on future way of life, on environment, on future urban morphology, on metropolisation process, etc. The life of a megaproject can easily attain 20 to 30 years between the political decision idea and the DUP (declaration of public utility). The commissioning process can also require several years. As a result, the socio-economic planning context permitting the definition of the project characteristics (method, capacity, on site development or new construction) is liable to change between the preliminary studies, the preliminary design file, the final draft design file and the commissioning.

The definition of uncertainty and risk which is used in this paper is the following : « *Risk is the possibility that events, their resulting impacts and their dynamic interactions will turn out differently than anticipated. Risk is typically viewed as something that can be described in statistical terms, while uncertainty is viewed as something that applies to situations in which potential outcomes and causal forces are not fully understood (...)* » (Miller, Lessard, 2008, p 148).

Different uncertainties and risks have been studied (Flyvbjerg, Bruzelius, Rothengatter, 2008; Miller, Lessard, 2008). They can be political (in the case of occasionally unexpected disagreements between the communities and the client financing the project), social (in the case of the project being challenged by associations or the public), institutional (in the case of changes to regulations impacting the project), financial (in the case of delays generating an added cost), or technical.

We make the assumption that uncertainties are not only negative and can also generate opportunities to improve the environmental and socio-economic assessment, the public consultation process and the planning documents.

First, the presentation define the categories of uncertainties and risks linked to the megaprojects. We distinguish the contextual uncertainties (as defined above) and the socially built uncertainties.

Secondly, we analyse the different impacts of these uncertainties and risks on the project and the decision making-process.

Thirdly, we analyse the opportunities that can be generated by these uncertainties and risks. We can distinguish middle term and long term opportunities. The middle term opportunities concern the decision making process and the project. For example new coalitions of actors can change and improve the objectives and the nature of the project. A new environmental law can lead to take into account more natural species and to adapt the location of the project.

We particularly focus on the long term opportunities which are linked to the project assessment, decision making process an planning tools. For example, the contestation of projects since the 90's and the greater influence of ecology leaded to open the decision making process to the public and to give greater importance to the multicriteria analysis compared to the cost benefit analysis.

Fourthly, we show different pistes to improve the tools of identification and analysis of uncertainties and specially opportunities, which may be sometimes confused with opposition and which are less studied.

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SHORT BIOGRAPHY

Geneviève Zembri-Mary is senior lecturer at the department of Geography of University of Cergy-Pontoise. She is the author of a habilitation thesis titled « Risks, uncertainties and flexibility of the decision making process and the planning process of transport megaprojects » and numerous articles about the identification, analyse, and treatment of uncertainties and risks in the planning process of megaprojects. She has worked with the Bartlett School of Planning -University College London on an international comparative research entitled « *Improving the treatment of complexity, uncertainty, and risk in the planning of urban mega transport projects face up to sustainable development challenges"* (financed by Volvo Research and Educational Foundation, 2006-13).

Translating Failures
The journey of framing government digitization as failing project[1]

Annalisa, Pelizza
Science, Technology and Policy Studies, University of Twente, Enschede, The Netherlands
* *E-mail: a.pelizza@utwente.nl*

GOVERNMENT DIGITIZATION AS MEGAPROJECT

Over the last thirty years programs aimed to digitize the public administration and the "government machine" [1] have conceived of administrative procedures' informatization as a driver for rationalization, innovation, and economic growth. The rationale is well-known: digitization will entail faster red tape, more efficient use of public resources, more effective and disintermediated services to citizens and businesses.

Digitization programs share characteristics with megaprojects. First, they require long-term investments and development plans. According to Margetts, government digitization has even a longer history than previously mentioned: "[t]he electronic element of government has been growing since the 1950s and 1960s when huge mainframe computers carrying out large-scale repetitive administrative tasks, entered the UK and US governments" [6]. Hence, digitizing government looks more an activity of government re-building, than of adding a digital layer [8]. Long development also depends on the difficulty to identify the contours of a technology. When new applications are thought to run on software frameworks developed in the 1990s, which are still re-used, it might be difficult to ascertain whether that is new or old development.

Second, both in government digitization and megaprojects anticipatory tools are put in place. Scenario building, for example, is the typical rhetorical format used by trans-national agencies to promote the adoption of e-government programs [7]. Also numerical modelling on cost savings is an established tool to foster e-gov programs, used mainly by consultancy firms.

Third, like other megaprojects, in many countries government digitization programs are questioned by non-specialists for the uncertainties they entail. Societal debates increasingly depict the digitization of the public sector as "a never-ending, expensive and uncertain process, and IT investments are often seen as an unjustified waste of public money" [9]. In the Netherlands, for example, a parliamentary commission was established to throw light on alleged annual losses of public funds in government digitization programs.

This presentation describes the journey of digitization programs as mega-failures by following how uncertainties were framed and translated among consultancy, media, parliamentary bodies, ministerial agencies in the Dutch context. It also proposes to recover the distinction between mediators and intermediaries as an analytical category useful for qualification.

THE "FAILURE" CHAIN OF TRANSLATION

The Dutch parliamentary commission on failing governmental IT projects was established in 2012, as an offspring of the "Future and Research Agenda 2012". The commission was tasked with reporting on the causes of the alleged high failure-rates in government digitization projects. Furthermore, it was expected to assess seven ongoing projects, and recommend methods to standardize their management.

The commission marked the parliamentary legitimation of IT-related uncertainties raised by non-political actors. In the Netherlands it constituted a point of no-return in the journey of digitization programs from innovation drivers to mega-failures. As such, this study analysed the commission hearings, together with ministerial decrees, newspaper articles, and expert blogs.

[1] The case discussed in this paper has been the object of a previous article: Pelizza, A. and Hoppe, R. (2015, Online First), 'Birth of a Failure: Consequences of framing ICT projects for the centralization of inter-departmental relations', *Administration and Society*. DOI: 10.1177/0095399715598343. The article developed a different argument than this paper, though, focusing on the relationships between government and media.

In the Dutch public debate IT-related uncertainties were first framed as "failures" by translation [2] of a consultancy research. In 2006 a U.S. consultancy report raised the issue that most IT investments worldwide (both in the public and private sectors) were completely unsuccessful in the 30% of cases, showed some kind of problems in the 50%, and were successful only in the 20%.

These worldwide results were recalled a few months later by a researcher at the university of Eindhoven, who calculated the expected value of unsuccessful projects (30%) starting from a total IT investment in The Netherlands of 18.5 billion euro. Of the resulting six billion euro, half were said to be unsuccessful investments coming from the public sector, on the basis of other calculations that divide the Dutch IT market between the private and public sector according to a 50% ratio. Thanks to this deductive reasoning, it was estimated that the Dutch government invested each year around three billion in unsuccessful digitization programs.

This calculation was made public by the researcher on a Dutch newspaper in June 2007, obtaining considerable attention nation-wide. When the article – titled "Automation Swallows Billions of Euros" [3] – appeared in the *Trouw* newspaper, its echo was such that the Lower House of Parliament was driven to investigate the causes of similar failure rates. On June 13, 2007, the first debate took place in the Lower House. Over the years, several audit initiatives followed up.

It is important to note that – following the professor's distinction between public and private investors, and the consultancy's definition of failures as mainly technical problems – the "failing IT programs" issue was framed by the *Trouw* article on two premises. First, that failures in information infrastructure were a government-wide problem and, therefore, should be addressed in a centralized way. Second, that government digitization programs were failing primarily because of technical causes.

First, in defining government digitization as a failure, the article referred to "all ICT projects" "in the government". That is, failures were framed as a government-wide phenomenon. Until then, there had been no comprehensive monitoring of IT programs at the governmental level: digitization had been considered the responsibility of individual ministries, not of Cabinet as a whole. The article, on the contrary, referred to a "partitive totality" [4]: an ensemble of distinct entities that can only be conceived in an aggregate manner.

Second, the article framed "governmental IT projects" as technical activities aimed at automating existing administrative processes. The article, in other words, identified failures as technical in nature (e.g., software bugs) [3], while it might also have mentioned different causes of failure, such as the non-use of perfectly running software [10].

Parliament accepted this reductionist frame unproblematized. No counter-frame was offered by parliamentary commissions to construct an alternative narrative. Hence, this framing pushed the Lower House to demand a (technical) overview of all governmental digitization programs, thus engaging in direct confrontation with the Cabinet. This in fact pre-selected and sharply reduced the range of solutions available to prevent future failures.

Parliament proposed the establishment of a coordinating role which a) was expected to report from a government-wide perspective (thus by-passing individual ministries), and b) was expected to report on all projects having some IT component (thus ambiguously extending control to almost any governmental activity). The new coordinating role was therefore endowed with purposefully centralizing functions: it was expected to achieve a panopticon overview of all government-wide digitization activities.

The decision on which actual actor should assume the coordinating role was driven by the newspaper framing, but also by financial and organizational logics proper to inter-ministerial relations. On one hand, being defined as government-wide, the "failing IT program" issue resonated with centralizing logics driven by financial imperatives already prevalent in inter-ministerial relations. On the other hand, the fact that the issue was initially framed as technical impeded political solutions, and facilitated operational ones, with the coordinator being chosen among operational managers, not politicians. As a result, a new Chief Information Officer was established, who operated at a unified governmental level, but from an operational management position.

In summary, the specific way the "failing IT programs" issue was framed across consultancies, academics, newspapers, Parliament commissions and inter-ministerial decrees had a major role in making certain alliances more likely, while hampering others. The whole-government encompassing and technical framing *shaped and pre-selected the landscape of possible alliances and inevitable deadlocks*; it steered the direction of action toward specific organizational solutions.

DISCUSSION AND CONCLUSION

The Dutch case shows that the way IT uncertainties were originally framed by the consultancy report informed the way they were translated later on in the chain of action, passing through media articles, parliamentary hearings, and Cabinet decrees. As Figure 1 shows, the consultancy report was the first to frame IT uncertainties as failures. The researcher's deductive reasoning calculated the cost of IT failures in the Dutch context my applying the failure rates to Dutch total IT investments. On its side, the newspaper article unified these two elements, crystallized them in a coherent framing and made it accessible to a broader audience. Parliament's un-problematized adoption of the framing *de facto* reinforced and legitimated it also in the political sphere. Finally, this established framing was further adopted in ministerial decrees shaping inter-ministerial relations.

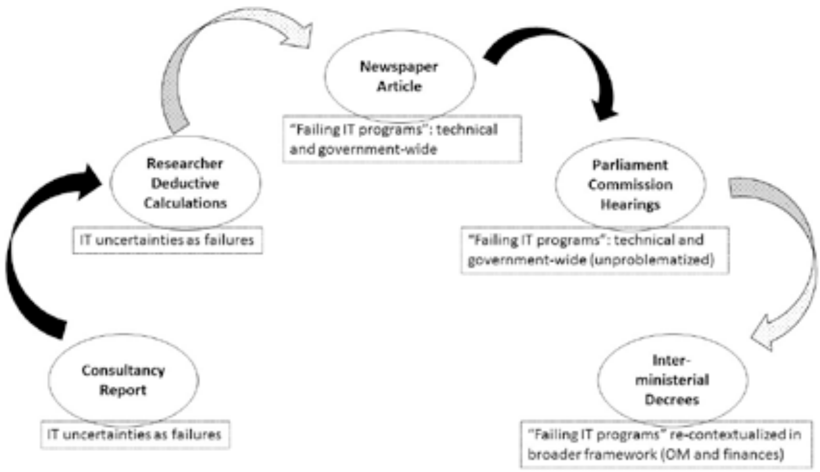

Figure 1: Translations of IT uncertainties across different texts. Patterned arrows indicate mediations, solid arrows intermediations

However, not all translations across different materialities and texts are equal. As Figure 1 shows by distinguishing between patterned and solid arrows, the researcher's calculation was limited to apply the consultancy's worldwide calculations to the Dutch total investments in IT. Diversely, the newspaper article crystallized the "IT uncertainties as failure" narrative, framed it as government-wide and technical, and translated it to a broader audience. By adopting the newspaper frame without problematizing it, Parliament did not add further elements to the translation chain: it just transported the frame from one sphere (i.e., media) to another (i.e., politics). Differently again, by including the "government failing IT programs" frame into the broader inter-ministerial discussion on centralization of operational management and financial recovery, Cabinet operated a further re-contextualization of IT uncertainties.

I thus suggest that this case can be fully described by recalling the distinction between intermediaries and mediators. Latour distinguishes "mediation" – a relationship that constitutes actors while taking place, from "intermediation" – a relationship where a tool just transports agency from one pre-existing point to another pre-existing point. While in intermediation the inputs are enough to define the outputs, mediation exceeds its inputs and cannot be reduced to a relationship of cause-and-effect [5].

In the case here described, consultancy, newspaper and Cabinet acted as mediators: they do not limit themselves to reproduce a former frame, but add some elements to it, either by introducing it (i.e., consultancy), by characterizing it (i.e., newspaper), or by re-contextualizing it (i.e., Cabinet). On the contrary, the researcher and Parliament acted as intermediaries: in their translation inputs were sufficient to foresee outputs.

In summary, this presentation contributes to the "Proving Futures and Governing Uncertainties" conference with an empirical case of qualification of uncertainties in information mega-infrastructures. Notably, it proposes to recover the long-standing between mediators and intermediaries as an analytical category to qualify technological uncertainties as patterns or modulations of mediations and intermediations.

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Front-end Analysis and Decision-making in Large Investment Projects

Knut Samset and Gro Holst Volden
Department of Civil Transport and Engineering, Norwegian Unversity of Science and Technology, Trondheim, Norway
knut.samse@ntnu.no, gro.holst.volden@ntnu.no

1 ABSTRACT

Public investment projects do not always meet the expectations of different stakeholders. Many are delivered too late, at a higher cost, and do not meet agreed quality standards. These are common problems that might have considerable adverse effect on operational costs and even the economic viability. In most cases, however, the long term effects of such problems are minor. The more serious type of problems associated with projects are when they are not able to produce the anticipated effect. Public resources are wasted. Clearly, a key to successful projects lies in the choice of concept.

This presentation is based on a study of 23 large Norwegian public projects aimed to explore strengths and weaknesses in the processes in the early phase before the final choice of conceptual solution is made and subsequent studies conducted by the Concept Research Program in Norway [1]. The projects studied include transport infrastructure projects, building projects and defence acquisitions. The focus is on deficiencies in the analytical and decision making processes, and the extent to which projects under study are *relevant* in relation to needs and priorities in society.

2 ANALYSIS AND DECISIONS

Projects evolve during their conceptual phase as the result of one analytic and one decision making process that run in parallel, figure 1. These are interdependent; decision moves analysis and analysis moves decision, stage by stage, aimed to translate the needs that motivate the initiative into a viable conceptual solution, which will eventually be implemented as a project.

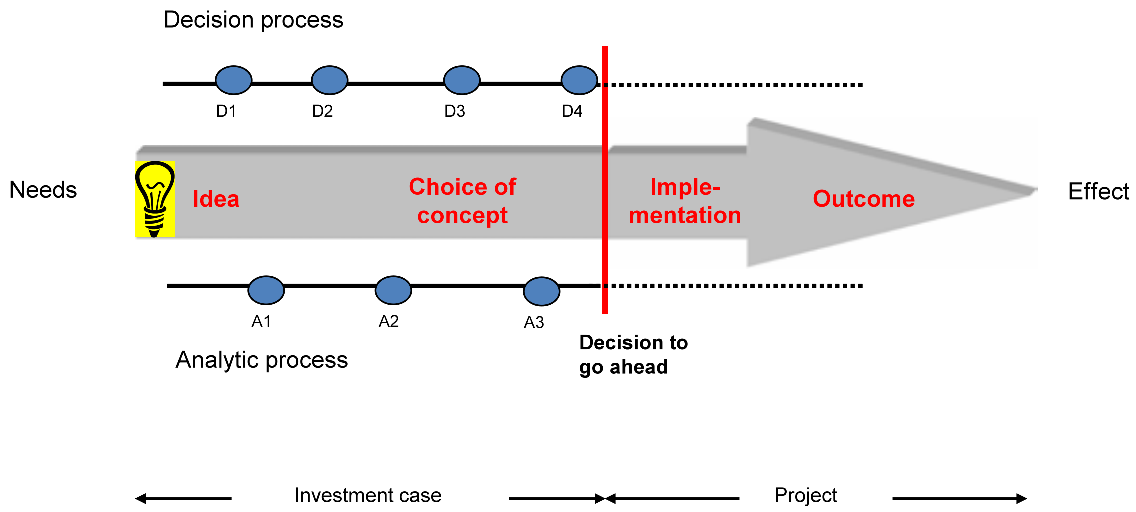

Figure 1 The front-end phase of a project is characterized by a series of analyses and decisions that run in parallel

The common understanding of what facilitates sound decisions and viable conceptual solutions is that the process starts with a broad and open view on what might be the preferences and possible solutions, and then homes in on what might eventually be the final choice. Systems analysis is one such approach.

However, the opposite is quite common; a specific project idea is taken as the point of departure, disregarding its obvious downsides, and without exploring alternatives. It could be because of inappropriate procedures and practices, the lack of relevant expertise to perform interdisciplinary analyses, or it could be the result of path dependency, which is characteristic of certain organizations strongly rooted in tradition. Other explanations, from political science and economics, could be found in the principal–agent problem and public choice theory [2]. These theories assume that those who come up with project ideas (public agencies, local authorities, etc.) are acting out of self-interest and therefore do not provide enough or correct information about the cost and benefits of the project.

Literature on project governance and project management offers a wealth of information on success factors, and factors that tend to affect projects adversely. See for instance [3], [4], [5]. A list of 12 common flaws in front end analysis and decision making were identified and applied in a study of 23 major public projects in Norway (100 million EUR - 5 billion EUR). They were chosen at random and included hospitals, warships, major facilities for culture, education or sport, roads, bridges, railway systems. A review of documentation, evaluation reports, media coverage and interview with key informants resulted in the aggregate assessment in Table 1. Projects with considerable flaws are marked with red.

	Project number																							Sum
Analysis	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	
Alternative concepts have not been scrutinized	X	X	X	X	X	X	X	X	X			X		X	X	X			X		X			15
Strategic underestimation of expected costs	X	X	X	X		X	X	X	X	X	X		X				X							12
Inadequate/limited analysis of problems and needs	X	X	X	X		X	X		X	X	X		X				X							11
Lack of realistic objectives and justification	X	X	X	X		X	X	X	X			X				X			X					11
Tactical splitting up and sequencisng of project	X				X		X		X	X				X	X			X	X		X			10
Predictable surprises not taken into account	X			X		X				X		X		X										6
Decisions																								
Disagreement regarding objectives and justification	X	X	X	X	X	X		X	X		X	X	X			X		X						13
Expert advice overruled by political preferences	X	X	X	X	X	X		X		X	X		X			X	X	X						13
Long lasting front end phase with shifting priorities	X	X	X		X		X	X		X		X		X			X			X		X		12
Repeated playoff in political decision process	X	X			X								X		X								X	6
Perverse incentives - benefits without liability				X			X	X							X					X				5
Political horse-trading between competing parties			X		X						X							X						4
Sum	10	8	8	8	7	7	7	7	6	6	5	5	5	4	4	4	4	4	3	2	2	1	1	
Relevance of the project																								

Table 1. There is a consistent tendency that projects that are considered relevant in relation to society's needs and priorities have less flaws in the analysis and decision making processes up front.

In terms of analysis the most common flaw in the projects was that alternative concepts had not been scrutinized. In more than half of the projects only one conceptual solution to the problem had been analyzed, and in cases where alternatives had been identified, it would typically be variants of the same concept only, e.g. alternative locations but essentially the same project concept, or replacements of the existing but in a new and improved version. This is what is termed path dependency, which could be observed in several defense projects: One series of frigates are being replaced by a new series of the same type of war ships, disregarding the fact that these were designed as escort vessels for large supply convoys during the Second World War and are essentially outdated in a modern warfare scenario, see figure 2.

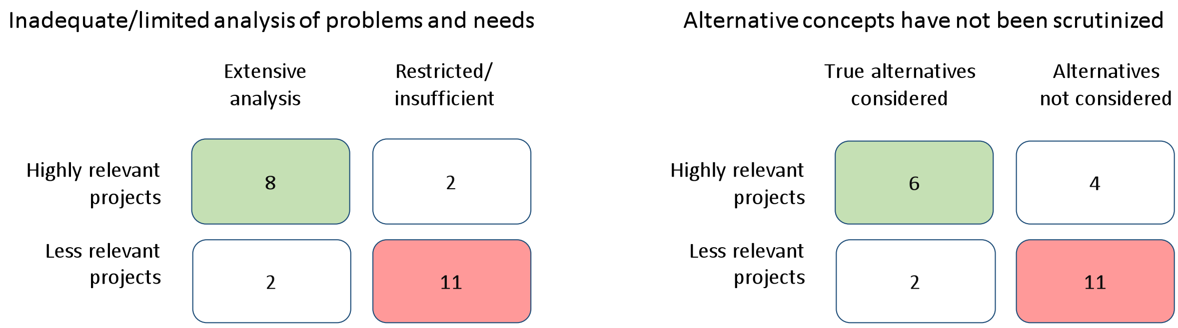

Figure 2 The two most common problems in up-front analyses

Another issue, which is strongly related, is the problem of inadequate or limited analyses of problems and needs upfront. This would typically result in unrealistic forecasts of needs, which in some cases could be considered as strategic overestimation of needs. Clearly, when costs are underestimated and needs overestimated, the needs/cost ratio is further overrated and provides decision makers with an even more biased basis for decisions. Half of the projects (11 cases) were found to have an inadequate or limited analysis of problems and needs.

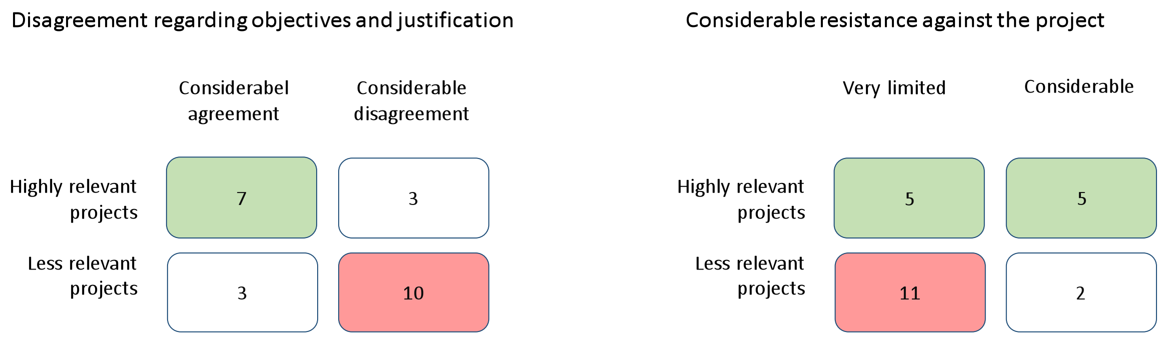

Figure 3 the two most common problems in the decision-making processes up-front

The most frequent problem seemed to be that there was a disagreement regarding objectives and justification of a project (13 cases), see figure 3. In one of the projects, the focus and justification shifted over a period of almost 30 years and the project became a hot political potato in a repeated tug-of-war between the state and regional authorities. Finally, we observed that resistance from the public against a project seem to have considerable effect, since only two of the less relevant projects that were contested were in fact implemented, while the majority (11 cases) that escaped the public radar were executed.

3 SOME ISSUES

The number of cases in this study is obviously too limited to warrant any firm conclusions. The results are hardly surprising but they raise a number of issues, for instance regarding project failures: (1) Is a faulty analysis automatically followed by a faulty decision process resulting in unsuccessful projects? (2) If so, could this have been avoided by a better analytic process whereby the bad projects were sifted out at an early stage. (3) Or is it an issue of faulty decision making from the very start, starting with the wrong type of problem to be addressed or the wrong type of conceptual solution? And (4) would the result of faulty analysis still be endorsed by decision makers or is it the decision makers that sort out the main problems and turn the situation around?

If we look at the successful projects, the questions would be: (5) Were they the result of systematic analysis, which was subsequently endorsed by decision makers without much ado? Or (6) is it simply an issue of starting off on the right foot with the right type of solution to the right type of problem?

This study cannot provide answers to these questions but experience suggests that there is a strong tendency to choose the initial concept and stick to it, almost regardless of how bad it is. Further, that there is an overwhelming inertia. Once the train has been set in motion – it is always impossible to stop. This goes a long way to explain the red projects on the left hand side. And we could add a third common tendency, incremental improvements of an inferior solution are preferred rather than fundamental change.

On the other hand, experience also suggests that the window of opportunities is usually larger than envisioned – and it is often largely unexplored.

4 CONCLUSIONS

The more fundamental problems that have to do with the project's strategic success could typically be traced back to the earliest preparatory phases, while the long term effect of problems which arise during implementation, such as of cost efficiency, delays and cost overrun, may be less significant. Challenges are to ensure a transparent and predictable process and avoid adverse effects of stakeholder's involvement and political bargaining. Typical issues to address are the problems of restricting the opportunity space, strategic underestimation of expected costs and risk, unrealistic justification and objectives, professional advice overruled by political preferences, perverse incentives i.e. benefits without liability, political horse-trading between competing parties, etc.

A number of features or archetypical weaknesses in the processes of analysis and decision- making have been identified. An essential finding is that the existence of such weaknesses is correlated with the project appearing to be less relevant with regard to societal priorities, needs and markets.

A prudent conclusion seems to be that the analytical part of the decision-making processes overall was rather weak, while the involvement of different stakeholders was considerable. The outcome of the projects varies even when formal rules for planning and decision making has been adhered to. This may to some extent explain both the success of some, and why other projects have been less successful. Experience suggests that a bad starting point may be adjusted through a successful decision-making process, even when the original idea was quite wrong. But also that in many cases this does not happen. Democratic processes, particularly those which take long time, are complex and difficult to predict, and many will claim that to tolerate decision flaws is necessary in a democracy.

If this is taken as a premise, this study suggests that the biggest potential for improvement lies in strengthening the analytical process. At the same time key actors need to acknowledge the problem that major projects are developed and planned in a haphazard and deficient manner, and that the conditions are not conducive to strengthen the analytical aspects. This is particularly challenging when it includes complex negotiating processes.

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Comparative assessment of uncertainties and risks associated with different disposal options for radioactive waste

Anne Eckhardt*
risicare GmbH, Zurich, Switzerland
* *E-mail: anne.eckhardt@risicare.ch*

INTRODUCTION

Passive safety versus active control is a frequent concern in public debates on the disposal of radioactive waste. Supporters of passive safety generally favour the final disposal in deep geological formations. Here, passive safety provisions counter uncertainties about future developments in society and nature. Supporters of active control often argue for a long-lasting surface or near-surface storage. Thus, it should be possible to counter at an early stage, amongst others, uncertainties that are due to deficient knowledge ('known unknowns' or 'unknown unknowns') or to adverse psychological and social mechanisms ('unknown knowns') which come into play while a disposal option is planned and facilities are built and operated.

The disposal in deep geological formations with arrangements for monitoring and retrieval promises to reconcile both positions. However, even this option raises questions on trade-offs between different types of uncertainty and risk, between active control and passive safety. For example, monitoring devices which reduce uncertainties about the safety-oriented development of the facility may impact the geological barriers, affect security and conflict with the safety-oriented objective to keep the disposal system simple and robust.

OBJECTIVES AND METHOD

The German platform for research 'ENTRIA – Disposal Options for Radioactive Residues: Interdisciplinary Analyses and Development of Evaluation Principles' shall include a safety-oriented comparison of different options for the disposal of high-level radioactive waste. Therefore, generic models of three disposal-options were designed, building up on the state of the art in science and technology. The options that are investigated are the final disposal, the disposal in deep geological formations with arrangements for monitoring and retrieval and the long-lasting surface storage. In the project 'Interdisciplinary Risk Research' within ENTRIA, our team described the development of the main activities linked directly to these disposal options and the development of the passive safety barriers involved in each option on the time line. Thereby, we partitioned the progress of each option into characteristic steps, like the site-selection phase, the construction phase or the operational phase. The content and duration of the phases was defined using current planning for disposal in Germany and supplemental international experiences, e.g. from the long-time surface storage-facility HABOG in the Netherlands or the site selection process for a deep geological repository in Switzerland. The detailed description of the development of the facilities and of activities linked directly to them served as a basis for the comparison of the options.

In order to obtain a safety-oriented comparison that is meaningful especially for political decision-makers we distinguish between the uncertainties and risks associated to each option. The exact differentiation involves natural-scientific, social-scientific and ethical reflections. In short, a risk exists if an adverse effect can occur or not occur with a certain probability. Uncertainty denotes a lack of information which impairs the assessment of a risk or makes it impossible. Calculable risks are risks whose adverse consequences and probabilities can be assessed in a quantitative or at least qualitative way. Diffuse and unknown risks are characterized by different grades of uncertainty which make an assessment of the risk impossible (Eckhardt and Rippe, 2016).

We evaluated the calculable risks and the uncertainties for each option in a structured way using verbal reasoning. A quantitative assessment was not feasible mainly because generic options were evaluated. While comparing the options, we focused on potential consequences on the life and the health of human beings, including psychosocial aspects of health.

For the calculable risks, a wealth of information from safety assessments and other safety-related documentation, e.g. on radiological or occupational aspects, was available. For the uncertainties however, only information about 'known unknowns' could be included.

'Known unknowns' exist when the persons involved, especially decision-makers, know that there are certain facts they do not know. Persons involved in safety assessments for instance know that they cannot foresee the probability and the potential consequences of human intrusion in a geological repository in the far future. Therefore, human intrusion in the far future is a 'known unknown'.

'Unknown knowns' are available facts and foreseeable developments which for different reasons are not considered. A prominent example provides the nuclear accident of Fuskushima Dai-ichi. After the accident, it became evident that the operator and the authorities had underestimated the seismic hazard as well as the tsunami-hazard at the site of the power plants. Evidence for greater hazards had existed before the accident, but it had been disregarded. After the accident, especially the historic marking stones in the region of Fukushima became well-known. They warned of building below the marks and indicated which tsunami heights had to be expected at the coast. 'Unknown knowns' can be managed by a good risk governance and safety culture (Eckhardt and Rippe, 2016, p.54f.).

'Unknown unknowns', finally, are not knowable in principle. 100 years ago for example, the importance of cyber-security for the functioning of critical infrastructures was an 'unknown unknown', because at that time the development of information technology could not be anticipated.

Table 1: Uncertainties and availability of information

	Information is available	Information is not available
Level of information is used	known knowns	known unknowns
Level of information is not used	unknown knowns	unknown unknowns

In the safety-oriented comparison, an option is ranked high if in the chosen time-period the uncertainties and the calculable risks associated to it are small. An outranking method was used to determine which option or which options in a certain period are predominant to others and the result was visualized on a 'risk map'.

CONCLUSIONS AND DISCUSSION

Our project in the framework of ENTRIA so far leads to the following insights:

- In many current discussions on the safety of different options for the disposal of high-level radioactive waste, calculable risks in the short and especially medium term are rather neglected in favour of considerations about long-term safety.
- Besides the calculable risks, uncertainty is a valuable assessment criterion for disposal options. This is supported by ethical reasoning but also by the observation that uncertainty is an important and frequent topic in public and political discussions on the safety of disposal options.
- In Germany as well as in Switzerland (ENSI, 2009), the main protection objectives for the disposal of radioactive waste are: 1. safety – to protect humans and the environment from harmful effects of the waste and 2. intergenerational justice – to avoid undue burdens and obligations on future generations. The reduction of uncertainty can contribute considerably to achieve both objectives.

- Methods for dealing with fundamental uncertainties about future developments, especially developments concerning human beings and society, are provided by the scientific discipline of technology assessment. Here, future developments are investigated under an analytical and interdisciplinary, sometimes even transdisciplinary perspective.
- In the nearer future – up to 30 years from the beginning of the realisation of an option – the calculable risks and uncertainties associated with the options 'final disposal', 'disposal in deep geological formations with arrangements for monitoring and retrieval' and 'long-lasting surface storage' do not differ very much. We assume, following the case-example of Germany, that this period is dominated by planning, site-selection and licensing for the geological disposal options and by planning, site-selection, licensing and construction of the surface disposal option. From the point of view of political decision-makers the safety-related consequences for each of the options in the next 30 years, which corresponds to a rather long-term political planning horizon, are roughly the same.
- In the medium term – between 30 and about 100 years from the beginning of the realisation of an option – the surface storage offers explicit advantages. These advantages result mainly because the facility can be realised faster than the geological repositories and is expected to operate on a higher safety-level than the conventional interim storage-facilities. Such interim storage-facilities are in the medium term still necessary, before the waste can be emplaced in a geological repository. Moreover many of the calculable risks and of the uncertainties related to the construction and operation of a facility in the deep underground are avoidable with a surface storage-facility, which is already in stable operation and needs only maintenance and backfitting. The requirement of resources and active safety provisions for geological disposal is higher than for the surface storage, mainly due to transports, packaging and emplacement of the waste. Therefore in this period uncertainties about the development of society are more relevant for the geological disposal options than for surface storage.
- After about 100 - 150 years, the final disposal-facility in geological formations will be closed, which might reduce the calculable risks considerably. However, there remain uncertainties about future human activities in the deeper geological underground. The facility in deep geological formations with arrangements for monitoring and retrieval will still be open for monitoring reasons. This state is associated with higher calculable risks for persons who stay in the neighbourhood of the facility as well as for persons working in the facility. If these disadvantages are compensated by the additional information gained from monitoring and a reduction of calculable risks and uncertainty from retrievability, has still to be clarified. How safe disposal will be realized after the operational period of the surface-facility ends, is absolutely open. Therefore the uncertainties for the surface storage become predominant after about 100 - 150 years. From today's point of view, in this period the final disposal is the favoured option. However the uncertainties related mainly to the development of humans and society are already overwhelming for each of the options.
- Due to great uncertainties, especially about societal developments in the mid-term future, the design of disposal options should be oriented consequently towards robustness and resilience. This concerns not only the natural and technical safety-oriented measures, where many provisions have already been made or are under the way, but also human, organisational and societal influences on the safety of disposal.

The final results of the project 'Interdisciplinary Risk Research' in ENTRIA will be published in 2017.

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SESSION 3 : Instruments, methods and tools

Chair: Pietro Marco Congedo

Uncertainties and confidence in climate projections: construction and inter-comparison of climate models

Jean-Louis Dufresne, Venance Journé
CNRS & Laboratoire de météorologie dynamique

The results of climate model projections have been at the core of the alarm about climate change since the 1980s. These models, derived from meteorological models, have been progressively improved and become more complex over the last thirty years. They are used to simulate and study the present climate, its evolution in recent years, in the distant past or its possible evolution in the future.

These models are partly based on well-established physical laws but:

- the difficulty of numerically solving the equations on which they are based;
- the complexity of the climate system;
- the complexities of the various models;
- and the differences between the results they produce;

raise questions about their validity and on the uncertainties and robustness of their results. In this presentation, we will show how, in practice, climate physicists aim at overcoming these difficulties in the construction of models on the one hand, and in the analysis of their results, on the other. We will discuss in particular the important role played by model inter-comparison projects in this approach and the role of scenarios.

Dealing with numerical uncertainties in the field of air quality forecasting and management

Author Name(s): Laurence ROUÏL[1*]
Institut National de l'Environnement Industriel et des Risques , Verneuil-en-Halattte, France
[*] *E-mail:* Laurence.rouil@ineris.fr

INTRODUCTION

Air quality is one of the most sensitive environmental domain, and also one of the most documented. Because of the harmful impacts of air pollution on human health and ecosystems, air pollution became, in Europe and in other countries a regulated field ruled by environmental objectives in terms of air pollutant emission ceilings, ambient air concentrations thresholds, etc… For instance, in the countries of the European Union the Thematic Strategy on Air Pollution (TSAP) sets short-term (2020) and long terms (2030-2050) objectives to reduce exposure to air pollution and the associated Directives frame the way to achieve them. Regarding monitoring aspects, it is noteworthy that the huge development of air quality monitoring networks all over Europe for the last decades, is now compensated by the implementation of air quality models that are considered as mature and reliable enough to play a role in policy support. Models are supposed to be economically interesting (in the sense that they are less expensive to maintain than networks of monitoring stations) but their main added-values rely actually on:

- The possibility to present results with continuous fields of the targeted variables (maps of air pollutant concentrations) which are much more readable than discontinuous sets of measurements at a discrete number of monitoring stations. General public is keen on getting maps to assess by themselves their exposure;
- Their capacity to forecast what should happen in the future, provided that they are fed by appropriate input data that are representative of the targeted future period;
- Their capacity to simulate situations that are not observed (scenarios) in the perspective of assessing the impact of emission reduction strategies or urban development strategies on air pollutant concentrations or the impact of new sources, etc…

So modelling is a useful and relevant communication tool on one side and helps in decision support on the other side. It became very popular in the community of air pollution management, and too often the question of the uncertainties is sidestepped. Modelling is by definition an approximation of reality (as monitoring in a sense) and inherent uncertainties must not only be accepted, but also taken into account in the decision. And it can be a challenging issue, especially in the air pollution management fields ruled by indicators that are based on thresholds (e.g. number of days when a given threshold of air pollutant concentrations is exceeded). In that case the concept of uncertainty becomes difficult to formalize, because the decision maker only wants to know whether concentrations are below or above the threshold. However, for the model, 1 or 2 $\mu g/m^3$ above or below the threshold is the same, and actually the results should not be so easy to endorse by the decision maker who needs to decide whether action plans should be taken or not.

Finally, at INERIS, our role, as expert and decision making support in the field of air pollution, has two faces:

- developing tools to limit and frame modelling uncertainty. It means improving the model parametrizations, their input, but also correcting their results by available data to elaborate a more reliable combined information (this is the objective of data assimilation processes).
- accompanying changes in the perception of non-experts (decision makers, general public) in the interpretation of modelling results: thinking in terms of probability rather than in terms of occurrence and accepting the uncertainty. In that perspective the way model results are presented (maps, histograms, graphs..) plays a very important role.

We propose to share the experience we developed for dealing with numerical uncertainties in the field of air quality forecasting and management. In particular, INERIS is the coordinator of the PREv'air system (www.prevair.org) the French air quality forecasting and mapping platform implemented in cooperation with Météo France and the CNRS, and we learnt a lot from this experience which is now running for almost 15 years.

ASSESSING UNCERTAINTIES IN AIR QUALITY MODELLING

Regional (national to European scale) air quality forecasting platforms are based so-called chemistry-transport models. INERIS uses the CHIMERE model (http://www.lmd.polytechnique.fr/chimere/) it develops together with the National Scientific Research Center (CNRS) [1]. A system like PREv'air [2], [3], based on numerical modelling and high performance computing, benefits from the wealth of observation data provided by local air quality monitoring networks for evaluating and correcting some products. Indeed, a complex and robust near real time and a posteriori verification framework has been defined to compare air quality forecasts provided by PREv'air with actual observations gathered every day from French and European monitoring networks, and to assess the uncertainties of the process. Such an approach, run for a significant time (more than 10 years), allows statistical corrections of some systematic biases of model results and make them more reliable. Actually PREv'air several modelling chains run every day for PREv'air : several versions of the CHIMERE model are run as the MOCAGE model developed and run by Météo France. The map published on the website is issued from the "best performing" model regarding statistical scores that are established every day and every years by the modelling teams (figure 1).

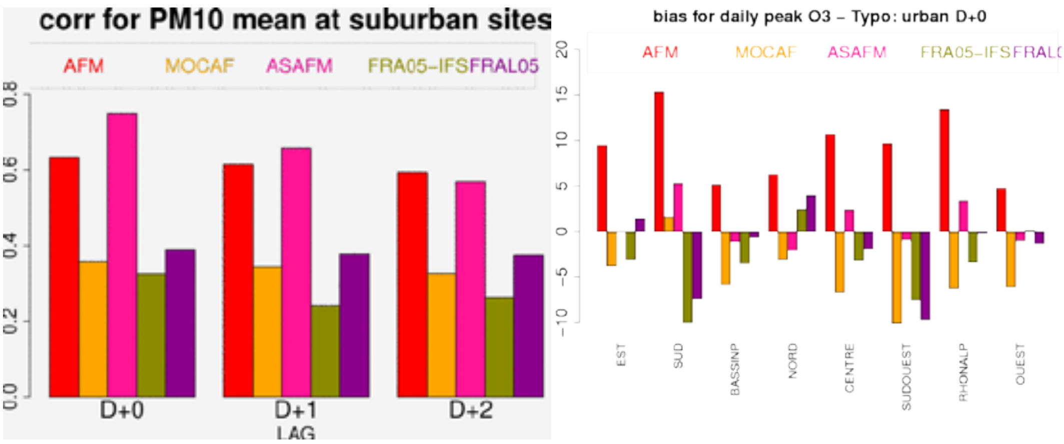

Figure 1: example of scores (correlation coefficient on the left, bias per French regions on the right) describing forecasting performances of the models running in the PREv'air system

The New Copernicus Atmosphere services or CAMS (http://atmosphere.copernicus.eu) implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) for European Commission and in which the PREV'air teams at INERIS and Météo France are deeply involved go a step further [4]. European air quality forecast. Seven European chemistry transport models are running every day to provide air quality forecasts and the dispersion of the model responses, which is considered as a possible representation of inherent uncertainty, is presented on so-called epsgrams (figure 2). Also, simulated or forecasted fields are compared every day to available observations (figure 3). Of course such an exhaustive evaluation of daily forecasts does not allow to ensure that prediction of future scenarios will be framed with the same uncertainty (because of the complex and non-linear physico-chemical processes that are in play). But it allows to understand strengths and weaknesses of the models, to improve their parametrisations, and to identify in which situations (specific periods, geographical regions) uncertainties are the highest. This information should ideally be presented to the policy maker for decision.

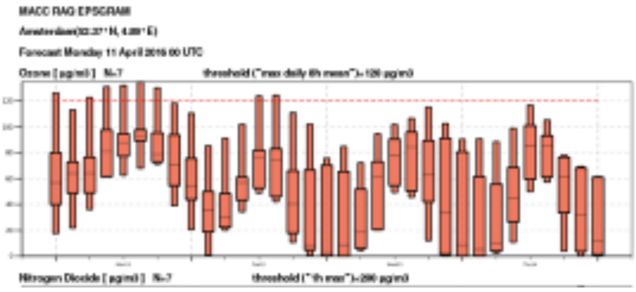

Figure 2: epsgram presenting the dispersion CAMS models responses to forecast ozone concentrations in Europe.

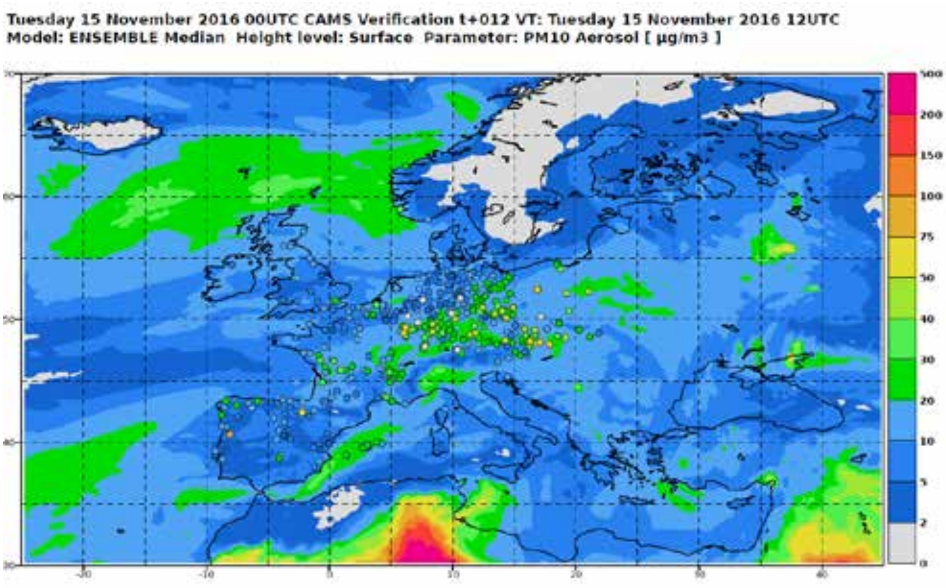

Figure 3: Verification of CAMS forecast of PM10 concentrations in Europe (15th November 2015). Colored dots represent monitoring stations and the concentrations actually observed

REDUCING UNCERTAINTIES IN AIR QUALITY MODELLING

A reasonable way to deal with this issue the solution consists certainly in characterizing air pollution events in terms of "likelihood of exceedance". We started to investigate such probabilistic approaches but some of them require important resources, for instance to run several air quality models (so-called ensemble approaches) or several model configurations to assess inherent modeling uncertainties. This is the approach adopted within the COPERNICUS framework, with the publication of air quality maps that result from the median of the results from the seven models involved in the provision of services. Experience shows that generally the Ensemble simulations are better, compared to observations than individual models results (figure 4). Ensemble approaches are very robust and provide good results but their implementation is very expensive since it requires running a significant number of models on the same cases. They are also largely used in other environmental fields (like weather forecasting or climate scenarios) and are certainly the most appropriate approaches to elaborate decision inputs to assess the impact of future pollution control strategy.

Modelling uncertainties can be reduced when assessing current pollution situation combining model results with available observations (provided that measurement uncertainties are controlled). Data assimilation techniques statistical adaptation approaches are more and more developed and new scientific challenges should arise with the development of new instrumentation: measurement devices and sensors will be cheaper, more portable and accessible (even for citizens). However, innovation coming along with this new generation of instruments will raise new uncertainties, and new questions about their use for model development.

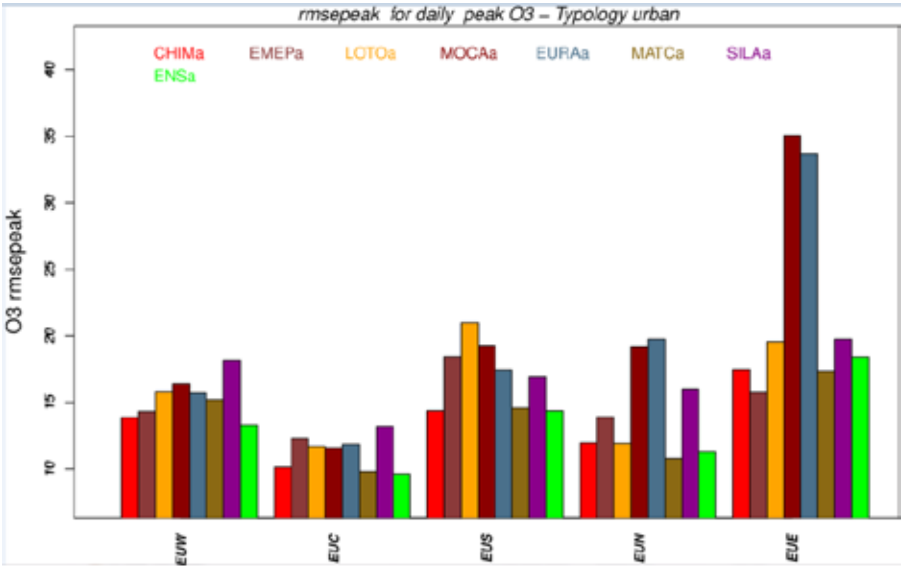

Figure 4: Root Mean Square Error calculated for 2014 ozone daily peak simulated by the seven chemistry-transport models involved in CAMS at urban stations. Ensemble results are in green. Results are discriminated by geographical region (Western, Central, Southern, Northern and Eastern Europe)

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Global Sensitivity Analysis Methods for Uncertain Stochastic Differential Equations and Stochastic Simulators

Olivier LE MAITRE

Stochastic models are used in many scientific fields, including mechanics, physics, life sciences, queues and social-network studies, chemistry. Stochastic modeling is necessary when deterministic ones can not capture features of the dynamics, for instance to represent effects of unresolved small-scale fluctuations, or when systems are subjected to important inherent noise. Often, stochastic models are not completely known and involve some calibrated parameters that should be considered as uncertain. In this case, it is critical to assess the impact of the uncertain model parameters on the stochastic model predictions. This is usually achieved by performing a sensitivity analysis (SA), which characterizes changes in a model output when the uncertain parameters are varied. In the case of stochastic model, one classically applies the SA to statistical moments of the prediction, estimating for instance the derivatives with respect of the uncertain parameters of the output mean and variance. In this presentation, we introduce new approaches of SA in stochastic system based on variance decomposition methods (ANOVA, Sobol). Compared to previous methods, our SA methods are global, with respect to both the parameters and stochasticity, and decompose the variance into stochastic, parametric and mixed contributions.

We consider first the case of uncertain Stochastic Differential Equations (SDE), that is systems with external noisy forcing and uncertain parameters. A polynomial chaos (PC) analysis with stochastic expansion coefficients is proposed to approximate the SDE solution. We first use a Galerkin formalism to determine the expansion coefficients, leading to a hierarchy of SDEs. Under the mild assumption that the noise and uncertain parameters are independent, the Galerkin formalism naturally separates parametric uncertainty and stochastic forcing dependences, enabling an orthogonal decomposition of the variance, and consequently identify contributions arising from the uncertainty in parameters, the stochastic forcing, and a coupled term. Non-intrusive approaches are subsequently considered for application to more complex systems hardly amenable to Galerkin projection. We also discuss parallel implementations and application to derived quantity of interest, in particular a novel sampling strategy for non-smooth quantities of interest but smooth SDE solution. Numerical examples are provided to illustrate the output of the SA and the computational complexity of the method.

Second, we consider the case of stochastic simulators governed by a set of reaction channels with stochastic dynamics. Reformulating the system dynamics in terms of independent standardized Poisson processes permits the identification of individual realizations of each reaction channel dynamic and a quantitative characterization of the inherent stochasticity sources. By judiciously exploiting the inherent stochasticity of the system, we can then compute the global sensitivities associated with individual reaction channels, as well as the importance of channel interactions. This approach is subsequently extended to account for the effects of uncertain parameters and we propose dedicated algorithms to perform the Sobol's decomposition of the variance into contributions from arbitrary subset of uncertain parameters and stochastic reaction channels. The algorithms is illustrated on simplified systems, including the birth-death, Schl\"ogl, and Michaelis-Menten models. The sensitivity analysis output is also contrasted with a local derivative-based sensitivity analysis method.

BIOGRAPHY

Olivier Le Maitre is a Senior Researcher (Directeur de Recherche) at the Centre National de la Recherche Scientifique (CNRS), France. In the past years, he has been visiting Professor at Duke University (North Carolina, 2013-2015) and visiting Faculty at the KAUST SRI-center on Uncertainty Quantification (2013-2016). He graduated in mechanical engineering and aero-thermo-chemistry at the University du Havre in 1995; PhD in computational mechanics at the University du Havre in 1998; Habilitation Diploma at the University d'Evry in 2006. From 1998 to 2007 he was Assistant Professor at the mechanical engineering department of the University d'Evry, Paris, before being appointed as full researcher by the CNRS and joining the LIMSI (Computer and Engineering Sciences Laboratory) in Orsay. He was promoted CNRS Senior Researcher in 2011. He has authored of more than 60 publications in international journals. His main research activities concern uncertainty quantification methods, computational fluid dynamics, and numerical approximation of PDEs, reactive and dynamical systems.

Quantification of uncertainties from ensembles of simulations

Vivien Mallet* and Isabelle Herlin
INRIA, Paris, France
E-mails: Vivien.Mallet@inria.fr, Isabelle.Herlin@inria.fr

INTRODUCTION

Decision making for environmental issues increasingly relies on numerical simulations and various observational data. However, the numerical models are limited by strong uncertainties because of poor input data and inaccurate physical, chemical, biological or mathematical modeling. Moreover, measurement instruments do not allow for a complete observation of environmental systems, and they often acquire noisy observations. Nevertheless, there is a strong need to optimally and jointly exploit numerical simulations and field observations for an objective assessment of risks on present and future times.

In this context, it is critical to quantify the uncertainties of all information sources (numerical models, empirical rules, fixed observations, mobile observations, qualitative observations) and to evaluate the best estimates that are derived from all the information. The final scientific products that may help decision-making are the probability distribution of the target quantities, confidence intervals or probabilistic forecasts.

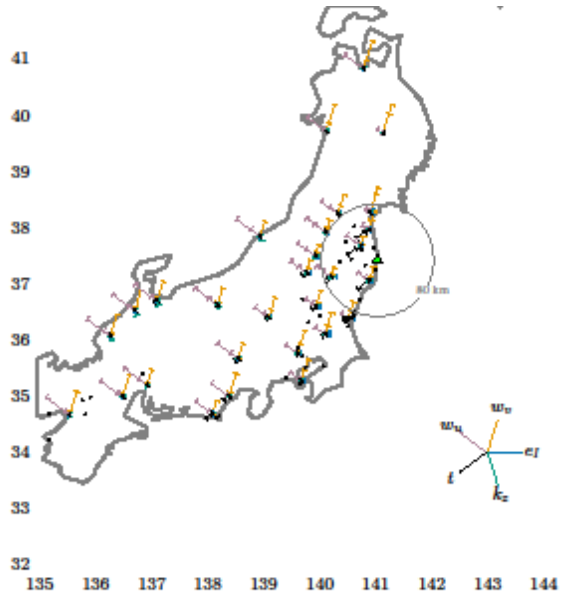
These various products can be derived from ensembles of simulations possibly combined with observations by the so-called data assimilation methods. The ensembles can be calibrated, including for the forecasts, in order to approximate the distribution of simulation errors. Such methods are for instance operationally applied for weather forecasting. The distribution of ensembles can be processed for a better quantification of the uncertainty. It is for instance possible to derive risk maps. Practical applications, like the protection of populations after a nuclear disaster as in Fukushima, can benefit from such risk maps, e.g., to determine an evacuation zone.

GENERATION OF ENSEMBLES

The accurate evaluation of the state of the environment tends to rely on numerical simulations and observational data. On the one hand, field observations often offer quality evaluations, but only at a limited number of locations and for a few variables. On the other hand, numerical models produce rich data including all state variables, at any location, for past, present and future times. Numerical models have reached a wide range of applications, from weather forecast to earthquake risk assessment, from urban noise pollution to flood cartography. However, a major issue for the use of these models for any decision-making lies in the high uncertainties they may be subject to.

The uncertainties in the numerical models come from various sources. The lack of understanding of the modeled phenomena leads to an approximate formulation of the processes. For example, not all chemical reactions in the atmosphere are accurately described. Even when the phenomena are perfectly known, they may not be all described by the model because of lack of data or unbearable computational costs. As a consequence, many models rely on subgrid parameterizations that approximately represent processes occurring at unresolved scales. For example, turbulence is not explicitly computed in large-scale dispersion models. Simulation models are also subject to the approximations of their numerical schemes, which can be high, especially for non-smooth states or fast varying phenomena. Finally, a well-known source of uncertainty lies in the input data to the models. Only part of the input data can be observed, and the rest is provided by uncertain numerical models or human expertise.

The combination of all the uncertainties sources often leads to high uncertainties in environmental applications. The uncertainty levels, which may easily reach 20% to 60%, are so high that the stochastic approach appears more suitable than the deterministic approach. Ideally, the complete probability distribution for the state of the target system should be computed. In practice, it is approximated by the sampling of an ensemble of simulations. This ensemble is generated so that it accounts for all uncertainties sources and properly represents the uncertainties on the computed state. In the best case, the ensemble is generated from multiple numerical models that provide plausible descriptions of the studied processes. The models should differ in their physical, chemical or biological formulation, they could rely on different mathematical formulations, and they may use various numerical schemes. The input data to these models are perturbed according to their attributed uncertainties, just like in Monte Carlo simulations. Also, alternative data sources may be used. Sensitivity analysis is sometimes applied to identify which input data are potentially the main uncertainty sources (See left image of Fig. 1).



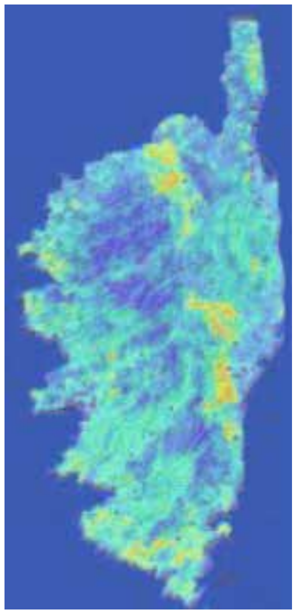


Figure 1: Left: Simulation of the dispersion of radionuclides after Fukushima disaster: representation of the input data whose uncertainties can influence the most the gamma dose rates. wu and wv are the zonal and meridional winds, eI is the emission of iodine, kz is the vertical diffusion, t is the emission time. Right: Risk map of fire over Corsica, for a given date in July 2009. This map is computed based on the burned-area distribution for the potential fires.

The computational cost of ensemble simulations may be too high in practical applications. The typical size of an ensemble is 50 to 100 members, although larger samples might prove their usefulness. Two main approaches are applied for cost reduction. In weather forecasting for instance, the models used to generate the ensemble are run at lower resolution than the traditional deterministic simulation. Another approach is meta-modeling where a model is replaced by an approximate model that runs much faster. The surrogate model can be automatically built by dimension reduction and statistical emulation [1].

CALIBRATION OF ENSEMBLES

Once an ensemble of simulations is generated, a key question is how well it represents the actual uncertainties. The only additional source of information that is available to decide on this question is observational data. However, an ensemble of simulations represents a probability density function while the observations can be seen as a realization of the simulated phenomena. Despite the difference in nature between the ensemble and the observations, there are scores that evaluate an ensemble using the observations. These scores can evaluate the resolution of the ensemble, that is, its ability to make distinct predictions for different subsets of events. They also evaluate its reliability, that is, the ability of the ensemble to produce a probability for an event that matches the observed frequency for that event.

It is rare that an ensemble of simulations shows good scores before a considerable amount of work has been invested in its calibration. Typically an initial ensemble is usually underspread because not all uncertainty sources are included and the actual uncertainties tend to be underestimated by modelers. The calibration can be carried out by optimization of an ensemble score. In the process, the distributions of the perturbations on the input data can be optimized. The models in the ensemble can also be given different weights depending on how likely they are assumed to be. Another approach is to generate a large ensemble and select a sub-ensemble that shows good performance.

Operational ensemble forecasting usually relies on the field observations, such as point measurements or satellite images, in order to improve the forecasts and reduce the uncertainties. The data assimilation methods merge the information included in the numerical model and the information given by the observations in order to compute an improved estimate of the system state and consequently an improved forecast. The Ensemble Kalman Filter (EnKF)[2] carries out the time integration of the ensemble of states, with the numerical model, and computes a new estimate of the states when observational data are available, according to the Bayes' rule. In the update equation, EnKF approximates the error variance of the state with the ensemble spread, and assumes Gaussian distributions on the simulated-state error and the observational error. This may result in spurious covariance values between distant locations of the spatial domain. Localization methods [3] are then usually applied in order to correct these effects.

Another approach to improve the forecast with observational data is the sequential aggregation of the forecasts ensemble. An aggregated forecast is computed as the weighted linear combination of the forecasts of the ensemble. These weights are derived from the past observations and ensemble predictions. Cesa-Bianchi and Lugosi [4] describe the use of machine learning algorithms for computing the weights values. An extension [5] was designed to produce a probability distribution instead of a single deterministic forecast.

OUTPUT PRODUCTS AND INTERPRETATION

Ensemble prediction systems provide a rich additional information compared to deterministic forecasting. This should support an improved decision-making. Various scientific products are computed from processing the ensemble forecasts in order to communicate on the uncertainty. Their significance should be accurately understood for an optimal use of these ensemble methods and a correct interpretation of their results.

The ensemble mean is obtained as the simple average of each variable across all ensemble members. It cannot be used as such, since it will not be able to describe the low probability events.

The discrete distribution of each variable, at each forecasting time, estimated from the ensemble of forecasts, is interpreted as the probability distribution of this variable. Its accuracy is usually evaluated with scoring rules such as the Brier score [6].

The ensemble of forecasts allows estimating the probability of a given event. For instance, if 80 out of 100 members forecast that the variable x will be greater than a threshold v, the probability of exceeding v is usually taken as 80%. These probabilities should be verified on a large set of past cases, in order to validate the adequacy between forecast probabilities and observed frequencies.

Risk maps (see right image of Fig. 1) are additionally produced by processing the forecasts ensemble. The probability of an event, usually a threshold exceedence, is multiplied by its cost for estimating the risk and supporting emergency measures such as evacuation for instance.

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About the treatment of measurement uncertainties in computer codes.

Pietro Marco CONGEDO

The intrinsic random character of the experimental data has to be taken into account when assessing the predictive character of the numerical prediction. In fact, experimental data are acquired by means of measurement tools, thus introducing an irreducible source of randomness. The question of computing confidence level in numerical simulation is especially complex in the context of flow simulation. Measurements in fluid mechanics devices are delicate and expensive due mainly to unsteadiness, turbulence, multiphase nature of the flow, and so on. This makes much more complicated the measures, thus increasing the amount of uncertainties associated, and makes the numerical simulation even more complex to solve.

Tough uncertainty quantification tools have acquired a certain maturity in the last years, the main challenge is still how to characterize uncertainties and how to implement them when the experiment and the numerical simulation are used together in order to learn about the physical problem of interest. In particular, the interaction between data and the input/output of the deterministic code has a strong impact on both the qualification and the quantification of the uncertainties. In this talk, we show how different ways of looking at the problem under uncertainties lead to different analysis and results, thus questioning the importance of how uncertainties are taken into account more than how uncertainties are quantified. The risk is to make some a-priori choices for treating uncertainties, which could lead to wrong analysis, thus deteriorating the capacity to take good decisions relying on this analysis. Our focus is on a problem of worldwide interest for the aerospace community.

Atmospheric re entry mission design is a complex although crucial step of any space mission. To insure the safety of the re entering crew the TPS (Thermal Protection System) must be properly sized and its physical characteristics well-known. Catalycity quantifies the molecular recombination rate that is a key-ingredient to accurately design the TPS. How rebuilding the TPS catalycity based on experimental results is still an open challenge for the aerospace community. In this talk, three different points of view are used to solve the problem. First, an engineering approach used by experimentalist and based on the use of safety factors is taken into account. Secondly, a classical way of including uncertainties through a computer code is used; in particular a non-intrusive spectral projection method is coupled with an in-house boundary layer solver, to provide error bars on the catalytic properties. This allows understanding which uncertainties have the largest impact on the error. Third, a Bayesian point of view is adopted in order to thoroughly derive the catalycity distribution along with all the unknown parameters for a given set of measures. Discussions about the underlying hypotheses and the associated results are then presented in terms of mathematical consistence and decision-making approaches.

BIOGRAPHY

Pietro Marco Congedo is a Research Scientist (CR1) at INRIA Bordeaux and team Leader of AQUARIUS (Joint Team from INRIA and Stanford University), devoted to uncertainty quantification methods for Computational-Fluid-Dynamics (CFD) simulation. He graduated with honours in Materials Engineering at University of Lecce (Italy). After his Master in Fluid Mechanics at Arts et Métiers (Paris, France), he received his Ph.D. in Energy Systems at University of Lecce in 2007, and he joined INRIA in September 2010. He has been awarded with the Best Paper Prize in Applied Aerodynamics of the AAAF (Association Aéronautique et Astronautique de France) in March 2009, research fellowships from Stanford University in 2010 and 2012, and the prize of scientific excellence from INRIA in 2012 and 2016. He is author of about 50 scientific papers, in international journals and books. His research interests are in intrusive and non-intrusive uncertainty quantification methods, robust optimization, and numerical simulation of real gas flows. He received several invitations for presentations in several Universities, in the context of International Schools and International Conferences. He co-organized the HONOM 2013 European Conference on high-order numerical methods, and he organized as Chairman the BOQUSE 2013, International Workshop on UQ and robust design optimization in Fluid Mechanics.

POSTER SESSION

Modeling the Future of Forests: how do models shape the interactions between managers and modelers?

Antoine Dolez
IRSTEA (Grenoble, France) & PACTE (Grenoble, France)
Antoine.dolez@irstea.fr

SUMMARY

Nowadays, forest practitioners and public offices (the National Forest Office, NFO) use more and more simulation models in order to try and improve forestry policies and write better forest management plans. Forest policies have to address numerous issues. First, all modifications in forests ecosystems take time to happen, so simulation can help practitioners to foresee the consequences of various forestry strategies i.e. species selection, tree planting or cutting. Second these strategies need to meet both productive and environmental requirements: productivity (withering woods) and sustainability (adaptation to Climate Change, including facing extreme climatic events like wildfire or water scarcity). In this perspective aggregation of different simulation models backed up with ecological sciences and local knowledges derived from the situated experiences of the practitioners are used to explore the various futures that would make it possible to conciliate these different imperatives and frame the associated uncertainties. My first objective is to address how models contribute to shape shared practices and cultures between managers and scientists [1]. My second objective is to understand how modeling and simulating practices deal with the inherent indetermination of understanding ecological systems [2] and how they embody visions of what science should be (ecological engineering, future-oriented practices).

My inquiry leans on several semi-structured interviews with modelers, practitioners and NFO's supervisors, meetings observation and on grey literature. The exploitation of the empirical material focuses on the role of models in the shaping, stabilization and functioning of networks of collaborations between researchers and managers and the development of shared ways of reasoning aiming to assess and design forestry policies. This presentation will focus on two levels of the scientific work.

My first example is a model simulating the evolution of tree-growth which was developed to understand how light intensities influence the growth of tree settlements; the model is called SAMSARA. While it was first focused on only one parameter – light intensity -, it now integrates more parameters such as climatic data and biodiversity indicators. This model was used to optimize the NFO's management: improving the cut strategies and training managers to utilize the model. This case-study allows me to characterize in details the future – and managing-oriented practices associated with this simulation model, and to see how scientists develop new practices in order to better consider management issues: new statistical methods, new collaborations, new data-sets… My second case-study is a simulation platform for forest growth (CAPSIS) which gathers about seventy models together. NFO's managers have access to this platform though a software and they can run simulations into it. This second case-study – although it is not disconnected from the other because managers have access to SAMSARA through CAPSIS – shows how a technological device and infrastructure – because CAPSIS is also collaboration's team – helps shape exchanges and dialogue between modelers and managers.

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Accounting for Uncertainties in Development of Post Closure Safety Scenarios

Lise GRIFFAULT and Daniel COELHO
ANDRA, *Safety, Environment and Waste Management Strategy Division*

INTRODUCTION

The French National Radioactive Waste Management Agency, or Andra, develops and implements disposal solutions for all radioactive waste generated in France. The protection of man and the environment must be ensured during the operation and in the long term, after closure of the disposal facility. Post closure safety is based on passive features.

In line with the Nuclear Safety Authority guidance of 2008 related to the geological disposal of high level and long-lived intermediate level wastes (Cigéo Project), the protection objectives are declined in two major safety functions (i) isolate the waste from man and environment and (ii) limit the transfer of radionuclides and toxics from the waste to the biosphere, over a period in line with the type of waste. After closure, the later function is itself declined in three safety functions: (a) preventing the circulation of water, (b) restricting the release of radionuclides and toxic elements and immobilizing them in the repository and (c) delaying and reducing the migration of radioactive substances and toxic elements released, from the packages and then from the disposal cells. The design of a disposal facility such as Cigéo is based on a breakdown of these functions and their allocation to the various components of the disposal system. Each function is translated into concrete requirements applicable to each component. An iterative approach between design and safety assessment makes it possible to progressively optimize the level of safety of the disposal facility and to consolidate the demonstration of this safety.

Andra's approach of post-closure safety assessment relies upon quantitative evaluation of scenarios in order:

- to verify compliance of the disposal facility to the safety objectives;
- to verify that the safety functions are realized using appropriate indicators;
- to verify the overall robustness of the disposal system.

Development of scenarios constitutes therefore the fundamental basis for the quantitative assessment as well as the choice of data and models when assessing the safety of a waste disposal facility.

Different types of scenarios are usually considered: a Normal Evolution Scenario (NES), Altered Evolution Scenarios (AES), and "What-if" scenarios. These types of scenarios are mostly based on international practices (see AEN workshop on scenarios held in Paris in June 2015), which distinguishes four generic categories for classification of scenarios:

1. Normal evolution scenarios that aim to represent the expected evolution of the disposal system taking account of certain or highly likely events or processes;
2. Altered Evolution Scenarios, representing events or processes that are less likely but plausible. They aim at assessing the consequences of the drift in time of the disposal system and check the lines of defence. They also aim at ensuring that the post-closure safety is always managed even in the event of malfunction of a component contributing to a safety function
3. "What-if" scenarios based on the very unlikely nature of the events considered, or based on conventional choices, to consider for example the loss of one or more safety functions. These scenarios are used to evaluate the robustness of the disposal system as a whole.
4. Inadvertent Human Intrusion Scenarios.

One key element to establishing scenarios is the handling of uncertainties, especially when addressing long time scales. Andra has implemented a specific Qualitative Safety Analysis methodology namely called "QSA" which links safety functions and scientific and technological state of knowledge and associated uncertainties at each stage of the project development.
The "QSA" aims at exploring possible dysfunctions of the repository components (waste package defects, seal failures,…), proposes design measures to reduce their occurrence within the framework of the above mentioned iterative process, and identify scenarios to be assessed.

The QSA analysis considers each uncertainty and examines if it may either (i) affect a component ability to perform a safety function, (ii) or have an influence on another component's ability to perform a safety function. The possible causes of dysfunction are then identified.

To master uncertainties or events of any type, "QSA" proposes either design measures or calculation cases through different scenarios (Normal Evolution Scenario, Altered Evolution Scenario, and What-if scenarios), see Figure 1.

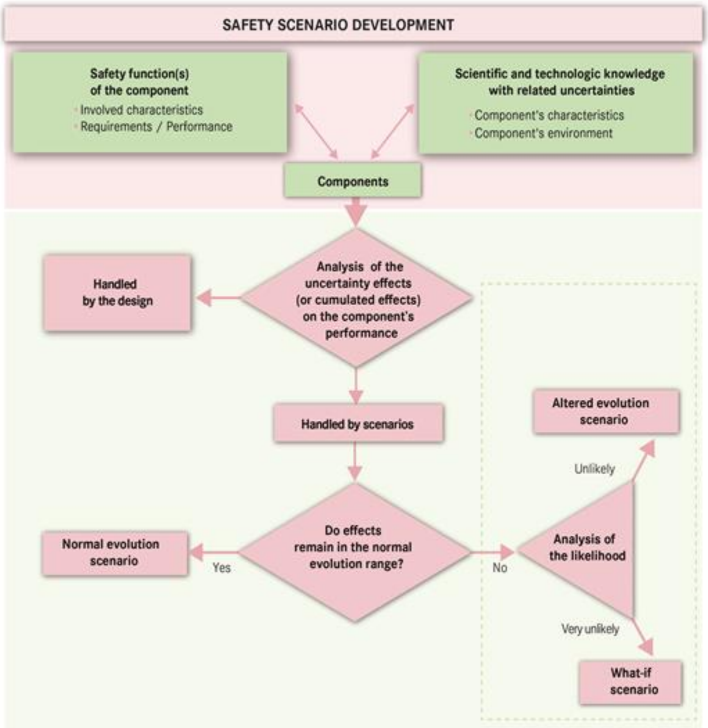

Figure 1: Schematic illustration of the different stages of a qualitative safety analysis and the link with the definition of the safety scenarios

To give illustration of this approach:

- Improvements of the repository design options in the form of technical measures can be proposed as necessary to make the system robust with respect to the uncertainties. For example, the use of simple materials with known behaviour (non-alloy steel, concrete, etc.) or the use of a leak tight disposal container to prevent uncertainties about the behaviour of the radionuclides at temperature;
- The choice of suitable values of parameters for the normal evolution scenario when the effects remain within the normal evolution range (see section below);
- The definition of other scenarios if the effects fall outside the normal evolution range.

The uncertainties analysed in the context of post-closure safety are mostly associated to the state of knowledge on:

- input data (radiological and chemical toxic waste inventory, the geological medium including the host formation, surrounding rock formations and hydrogeology, and biosphere);
- intrinsic characteristics of the engineered repository components and technological issues;
- processes governing the repository's evolution, from the repository closure to the long term (thermal, hydraulic, gas, mechanical, chemical, radiological and biological processes and their coupling);
- technological uncertainties;
- external events such as climatic conditions and geodynamic evolutions.

The overall QSA relies upon the understanding, and modelling of internal processes (and their coupling) and external events from the closure to the long term (up to one million years). The knowledge acquired since about twenty years allows to have for the characteristics and the processes represented in the scenarios : (i) of reference values defined considering the most representative conditions, (ii), of minimal and maximal values considering residual uncertainties, and (iii) of the corrective factors if necessary.

The overall approach enables to take into account uncertainties which effects are still within the normal evolution range described by the following situations:

a reference situation which considers the disposal as designed and is based on a set of assumptions and data whose selection logic is to adopt those that rely on the best available technology;

a situation based on the post-closure safety requirements applicable to Cigéo and conservative data when no specified requirements exist.

From the results of QSA, these different situations take into account uncertainties as follow:

<u>for the reference situation</u>, data are selected on the basis of the best scientific and technical knowledge available. In this context, the characteristics and processes with the most solid scientific support are generally chosen. However this situation considers a certain conservatism as a function of residual uncertainties at this stage;

<u>for the situation corresponding to the requirements applicable to Cigéo</u>, the data correspond to the values as defined for the post-closure safety requirements or performance. If no requirements have been specified for certain characteristics of the components contributing to the safety functions, assumptions and data corresponding to "conservative" limits of the knowledge available are used (e.g. choosing conservative values for the parameters). This representation is described as "bounding" but the concept of bounding in this context does not mean that it ensures the impact is taken into account pessimistically, but that it corresponds to the operation of the repository as specified in the requirements applicable to Cigeo.

Concerning altered evolution scenarios and what-if scenarios, the identified potential causes of component failures that could lead to significant degradation of a component's performance or the loss of a safety function that would bring the disposal system out of the normal evolution range, are analysed through qualitative judgement in order to make a link with the classification of scenarios:

- if the identified causes of the failure are unlikely, then altered evolution scenarios are defined. They aim to evaluate the consequences of the disposal system deviating over time and to check the lines of defence;
- if the causes of the failure are very unlikely, "What-if" scenarios are defined to test the robustness of the disposal system on the same basis as the additional safety assessments used for safety in operation.

In that case, the analysis also look at certain combinations or accumulations of uncertainties, focusing on the effects of potential aggravating accumulations as part of the "What-if" scenarios. The analysis also leads to the exclusion of scenarios considered implausible, resulting from an accumulation of two causes of failure that are completely independent of one another.
A set of scenarios is then developed to provide a description of the calculation cases to be quantified. A set of indicators (dose but also transfer pathways, radionuclides flows through components…) are evaluated for compliance with safety objectives and performance assessment of the disposal system. Biosphere doesn't have any safety function but it constitutes the last step for evaluation of the dose. A specific method based on the IAEA BIOMASS project is used to handle uncertainties associated to this component.

CONCLUSION

The "QSA" offers an integrated and structured analysis of all uncertainties in order to evaluate their potential impact on post-closure safety functions. It explores if any residual uncertainty associated to a component (waste packages, seals) can affect its capacity to fulfil a safety function and/or to achieve its specified performance or have an influence on the ability of another component to fulfil a safety functions. It therefore conducts to propose a management of the uncertainties, either by design or through the definition of a set of scenarios to be quantified.

It is also a tool for justification of the structural choices for the representation of the components in the scenarios and the characteristics to consider in the quantitative evaluation (choice of conservative or not values of parameters).

The use of Evidence Support Logic (ESL) to structure and present knowledge and uncertainties in order to assess confidence in decisions

Alan Paulley*, Richard Metcalfe**, Kate Thatcher***, James Penfold****
Quintessa Ltd
* alanpaulley@quintessa.org, +44 1925 885 952
** richardmetcalfe@quintessa.org, +44 1491 630 055
*** katethatcher@quintessa.org, +44 1925 885 959
**** jamespenfold@quintessa.org, +44 1925 885 958

OVERVIEW

Large technological and infrastructure projects are often complex and associated with uncertainty, especially where they involve a combination of man-made and natural systems. Facilities for the underground disposal of radioactive wastes represent an important class of such systems. It is important that confidence in chosen designs, future performance, safety and environmental impacts can all be demonstrated to a range of different classes of stakeholders, taking account of the uncertainties involved and showing how the overall outcome is robust to them.

In order to provide a justified interpretation of the available evidence, which can be audit-traced from start to finish, it is necessary to judge transparently both the quality of the data and the quality of the interpretation, associated modelling processes etc. A systematic approach to the assessment of such evidence therefore allows the levels of confidence in such data to be quantified and justified.

The technique of Evidence Support Logic or ESL was developed in the UK but has been used in a number of industries in Europe, the USA and Japan. It is intended to support decision makers and modellers in their sense-making when faced with extensive information processing requirements. ESL involves systematically breaking down the question under consideration into a hierarchical hypothesis model (an ESL 'tree'). The elements of such a model record basic judgements and opinions relating to the quality of evidence associated with a particular interpretation or proposition.

Judgements on confidence in classical probability theory require confidence to be either in favour of a hypothesis, or against it. This is sometimes described as a 'closed world' perspective, in which confidence 'for' and confidence 'against' are treated as complementary concepts. However, ESL uses 'three-value logic' allowing for a measure of uncertainty as well, recognising that confidence in a proposition may be only partial and that some level of belief concerning the meaning of the confidence may be assigned to an uncommitted state. By clearly and independently representing evidence for and against a proposition at the 'leaf' level of a tree and using appropriate propagation parameterisation, ESL allows the impact of uncertainty in key supporting arguments to the main decision being made to be represented and interpreted.

Key concepts include:

- The 'sufficiency' of one hypothesis, if proved (or disproved) to provide confidence in the success (or failure) of the 'parent' hypothesis it supports – essentially a conditional probability;
- The level of confidence that the evidence base provides both for and against 'leaf' or child hypotheses, based upon the coverage, quality and face value of the data set;
- Where logic dictates that there must be confidence in *all*of a set of hypotheses for there to be confidence in their parent (or conversely, confidence against all of a set of hypotheses to disprove their parent);
- Logic concerning situations where *any* of a set of hypotheses may dominate the provision confidence for (or indeed against) a parent hypotheses;

- Identifying where a minimum level of confidence in a particular hypothesis or set of hypotheses is necessary for confidence in a parent (i.e. a confidence threshold applies).

Together, these concepts, represented in ESL and underpinned by the audit trail, can be used to model key decisions and situations in order to understand and demonstrate where confidence needs to come from to make a robust choice.

ESL can therefore help confidence-building arguments and communication of the reasons for that confidence, for complex projects. It can also help stakeholders understand the reasoning for decisions, in particular where those stakeholders are involved in some part of an open, deliberative process to assemble the ESL model.

IMPLEMENTATION AND APPLICATION

ESL, and a graphical representation of it implemented in Quintessa's TESLA code, can be used to present the main lines of reasoning for a judgement and the key issues and uncertainties associated with them, whilst linking directly with the underpinning audit trail, including both quantitative and qualitative arguments. This includes using a range of plots including 'tree' plots, sensitivity plots, plots exploring the importance of different hypotheses to the top-level hypotheses, and other graphical illustrations to help understand and illustrate the outcomes and the relative importance of key evidence sources and uncertainties. A key aspect of supporting tools is also the representation and organisation of the audit trail, allowing users and stakeholders to click through from the graphical representation of the level of confidence the evidence provides in a decision to the underpinning knowledge base, including qualitative assessments, quantitative data, and related judgements.

An example area of ESL application concerns site selection for radioactive waste repositories, and the development of site characterisation data sets. At the start of a siting process, there is often a basic knowledge of the geological and hydrological / hydrogeological conditions associated with sets of candidate sites. As the site selection process progresses and sites are ruled out (e.g. on technical and/or socio-economic grounds), characterisation effort may increasingly focus on a smaller number of sites. This characterisation effort will progressively reduce the uncertainties associated with the key characteristics of the site relevant to its potential to host a repository. Combined with increasing knowledge on potential wastes and associated treatment, containerisation, backfill and engineering concepts, this enhanced knowledge will progressively reduce uncertainties concerning the suitability of sites for the wastes. However, uncertainty in key characteristics will always remain.

The ESL approach can be used to track the increase in confidence in understanding and suitability of a site, and the associated progressive reduction of uncertainties, with increasing collation of data. This helps clearly present the confidence that is available in the potential suitability of a particular site on the basis of available data, and the areas of uncertainty that remain of importance. This therefore provides a helpful communication and prioritisation tool. Demonstrating to stakeholders that certain uncertainties are more important to target than others in terms of improving overall confidence in the future performance of a site can also be a significant step in gaining buy-in to a programme. By viewing different instances of the same ESL tree with time as knowledge develops, the value of information gathering and characterisation activities can be clearly shown. Also, by comparing more than one different site assessed using the same tree, it is possible to understand which site offers the best technical prospect in terms of confidence in meeting all the disposal system requirements. This approach has also been used in other industries, e.g. in site selection for proposed geological carbon dioxide storage systems.

The ESL approach also has applications for decommissioning programmes and other operations that may generate waste for an existing or proposed disposal facility. For example, the characteristics of a waste associated with a legacy facility may be uncertain due to incomplete or missing data when compared with the data requirements of a modern disposal facility. ESL however can help assess the level of confidence provided by the available data that the wastes will be able to meet certain disposability requirements. An appreciation of the remaining uncertainty associated with those requirements can then be used to either prioritise further characterisation activities before retrievals, and/or can be used directly in risk assessments to help characterise the potential risks associated with proceeding directly, for example if it is not practicable to undertake further meaningful characterisation.

EXAMPLES OF INNOVATIVE APPROACHES FOR MAXIMISING THE VALUE OF DATA FOR AN ESL APPROACH: PROCESS INFORMED STATISTICAL MODELLING

One of the key strengths of ESL is that it can be used to assess a wide variety of quantitative and qualitive sources of information together, evaluating the sum extent of the confidence that those various evidence sources provide to the overall outcome. However the information base on historic wastes or indeed on future waste projections can be sufficiently sparse or uncertain as to cause significant challenges when using it to make decisions. This can be because the information was not collected for the purpose of the decision now being made, or if it is limited due to the confidence available in forecasts.

Often data-set issues can be addressed using process based modelling by matching model outcomes to observed data in order to allow data interpolation and extrapolation for future evolution. In other cases, 'standard' statistical approaches can be appropriate for interpolating within the existing data should the available information be suitable for this approach.

In some cases, projections outside the existing data range may be necessary to support decisions. In such cases a different way of addressing the problem can be helpful. A very powerful tool includes statistical modelling using physical understanding to obtain maximum information from small, uncertain or variable data sets. This approach brings together process understanding with statistical modelling to make the most of the available data and has significant advantages over standard methods especially when making predictions/forecasts outside the range of the available data.

Process informed modelling can prove very successful and cost effective in gaining the maximum possible value out of sparse and uncertain data. The approach can also help explore and separate the impacts of variability from those arising from sources of uncertainty.

Such statistical approaches help to provide underpinned probability-informed interpretations of data and extrapolations that can be of benefit to ESL and indeed other processes. This is not the same as a 'probabilistic' approach but is a process-informed statistical analysis can be of substantial assistance in deriving defensible probabilistic distributions for key properties and parameters.

FURTHER EXAMPLES OF THE USE OF ESL

Other examples of the use of ESL from the nuclear industry including its application to the Hanford Tanks, applications to understand the potential performance of options to mitigate any future leaks from legacy storage facilities, consideration of options to manage or remediate subsurface waste disposals for which no emplacement records are available, and applications from other industries including brine cavern stability and long-term underground storage of carbon dioxide. These provide useful case studies demonstrating the value of the approach.

AUTHOR BIOGRAPHIES

Dr Alan Paulley has spent 19 years providing strategic decision and assessment support to projects in the nuclear and other industries. He specialises in helping clients make decisions for complex systems subject to uncertainty, in particular for projects with stakeholder interest. Experience ranges from national strategy development processes for key radioactive waste streams to decommissioning decisions for hazardous legacy facilities, and repository design, optimisation, assessment and safety.

Dr Richard Metcalfe is a Chartered Geologist who has 26 years' experience of safety /performance / risk assessments in the fields of radioactive waste management, underground CO2 storage, salt cavern stabilisation, and underground gas storage. He has contributed to projects in the UK, other European countries, North America and Japan. Structured decision support and uncertainty management has been a key component of Richard's work.

Dr Kate Thatcher primarily works on numerical modelling of coupled thermal, hydraulic and mechanical processes in radioactive waste disposal facilities for the UK, French and Swiss programmes. She helps clients to understand which processes within these complex systems are key to ensuring the safety of the disposal system.

Dr James Penfold is a Chartered Radiation Protection Professional who has particular experience and expertise in the development of strategies for the management of radioactive wastes, nuclear site End State definition and the management of low activity contaminated land. This includes structured decision support and environmental safety case development for clients in the UK, Europe and Canada.

Long-term confinement of highly radioactive waste

Guillaume Pepin, Jean-Charles Robinet, Stéphan Schumacher
ANDRA, *Research and Development Division*

Geological disposal is widely considered by the scientific community as the best alternative to reduce the long term risk of highly radioactive waste. To this respect, it is neither possible nor necessary to do an exact prediction of radionuclide transfer up to one million years, thereby proving that normative dose/risk criteria will never be exceeded in such a long-term period of time. Nevertheless, various anticipatory tools and devices are involved in the production of scientific and technical knowledge informing the repository safety demonstration at this timescale.

« Strong statements » based on scientific laws, if not predictions, can be made in the long run for some processes like radioactive decay, solubility limits, adsorption onto minerals surfaces, and others. Their applicability to the complex system of a nuclear waste repository poses however fundamental questions concerning the diverse related uncertainties. Our proposal aims to address this issue in a perspective different from that focusing on uncertainties reduction, and show mainly how these scientific and technical instruments interface with each other in consistent ways.

Our poster will shed light on the various "pieces of evidence" that have been assembled to make proof at different scales of time and space for the Cigéo project in the particular case of the geological disposal of nuclear waste glass. For example, the confinement properties of the glass matrix assessed in chemical terms, by means mainly of laboratory experiences made at the atomic scale, are crucial for the first disposal period, whereas analogy contribution is more important afterwards. The adsorption properties of the surrounding clay-rock considered as one of the main phenomena involved in the long-term confinement of radionuclides can be evidenced through a large set of methods, experimental tools and natural observations including molecular dynamics, batch adsorption experiments and natural analogs. More specifically, transfer of ^{36}CL will be followed in time and space according to a wide range of scientific and technical instruments. In so doing, we will stress the processes by which technical options and scenarios-based decisions are informed and how upper-level framings and demands feed-back inversely the knowledge bases.

The requirements for the written abstract are the same whether it was accepted for an oral presentation or poster. All extended abstracts will be included equally in the conference proceedings.

Guillaume Pepin is Head of the Performance Assessment Department at Andra's R&D Division

Dr. Jean-Charles Robinet is a specialist on transfer of radionuclides and chemo-toxic in the geosphere and materials and Head of the Transfer Unit at Andra's R&D Division.

Stéphan Schumacher is Head of the Packages and Materials Department at Andra's R&D Division

Contribution of Civil Society to Safety Culture and Conditions for Public Engagement along the Safety Case Review Process of Geological Disposal Facilities

Maryna Surkova[1], Koen Mannaerts[1], Stéphane Baudé[2],
Yves Marignac[2,3], Frédéric Bernier[1], Delphine Pellegrini[4]
[1] Federal Agency for Nuclear Control (FANC), Department of Establishment and Waste, Radioactive Waste Management Group, Ravensteinstreet 36, BE-1000 Brussels, BELGIUM
[2] Mutadis Consultants, 5 rue d'Alsace, FR-75010 Paris, FRANCE
[3] WISE-Paris, 31-33 rue de la Colonie, FR-75013 Paris, FRANCE
[4] Institut de Radioprotection et de Sûreté Nucléaire (IRSN), BP 17 - 92262 Fontenay-aux-Roses Cedex 31, FRANCE
E-mail: Maryna.Surkova@FANC.FGOV.BE

ABSTRACT

For the past few decades, the need for reinforced information and effective engagement of civil society in decision-making, notably on matters concerning management of environment has become a primer topic for various research projects across the world. In this article, the results of the SITEX-II project [1] related to the interactions with civil society along the safety case review process of geological disposal facilities are presented. The main challenge of the aforementioned project is to propose compelling and objective approaches for closer interactions with civil society in the field of radioactive waste management. With the help of a questionnaire and workshops, the main commonalities and differences on vision on safety culture by institutional and non-institutional actors have been identified together with conditions and means necessary to engage civil society along the decision-making process of the safety case review.

KEY WORDS

Radioactive waste management, public engagement, safety principles, safety culture.

INTRODUCTION

The European Council Directive 2011/70/EURATOM of 19 July 2011 [2] establishes a Community framework for the responsible and safe management of spent fuel and radioactive waste. As well as reinforcing the role and independence of the competent regulatory authority, the Directive [2] identifies the need for civil society contribution and participation to enhance the quality of the decision-making processes concerning radioactive waste management.

In 2012, the EURATOM FP7 launched a 24 months project called SITEX [3]: 'Sustainable network of Independent Technical EXpertise for radioactive waste disposal', the objective of the which is to set up a network capable of harmonizing European approaches to technical expertise in of geological repositories for radioactive waste. The successful performance of SITEX led to the establishment of the SITEX-II project. SITEX-II brings together 18 organisations from 12 countries representing regulatory authorities, Technical Supports Organisations (TSO's), research institutes, an education institute, as well as specialists in risk governance and interaction with general public, including civil society organizations (NGO's) closely involved in the nuclear waste management activities. According to the perspective developed by the SITEX project, transparency of the decision-making process includes several requirements such as to maintain over time, consultations and interactions with interested parties in the decision-making process, in particular with the civil society; ergo one of the important challenges for the later project becomes the investigation and establishment of the concrete approaches for improvement of the civil society engagement process along the safety case review of the geological disposal facilities, in particular.

The work package within SITEX-II, devoted to the interactions between institutional experts and civil society, investigates the questions of how safety culture can be shared through different interested parties and what the concrete conditions and means necessary for efficient public engagement are. To perform these tasks a questionnaire has been developed and a set of personal interviews (in particular, 27) with various representatives of non-institutional (NGO's) and institutional actors in Europe (regulators, TSO's, researchers) has been performed. The goals of this assignment are to identify the main commonalities and differences in the vision on safety culture in radioactive waste management and to investigate the expectations of non-institutional as well as institutional actors regarding the engagement of civil society in the safety case review of geological disposal facilities. The methodology applied to analyse the answers was, firstly, to compare, quantitatively, the most frequently used words and common expressions in the answers of the two interviewed groups and note the similarities and differences. Subsequently, the qualitative analyses included a systematic study of the interviewees' vision on the issues in question, so that the actual differences and commonalities in the perception and understanding could have been fairly recognized. The workshops organised along the project helped to refine and clarify the results of the performed analyses.

FINDINGS

Safety and safety culture in the era of complexity and networks

Deep geological disposals are complex sociotechnical objects that aim to achieve safe disposal of radioactive waste through a combination of technological artefacts, scientific constructions, natural entities and social and cultural constructions. Their safety relies on an active phase that is likely to last at least a century and a longer-term passive phase in which safety does not rely on a human contribution anymore. As for German philosopher Niklas Luhmann [4], such complex systems entail risks of obsolescence associated to dynamics of compartmentalisation and fragmentation [5] which compromise the capacity of complex systems to adapt to changes, ruptures, and evolutions of the world that are likely to occur along the period of active safety management.

Safety culture is a framework to coordinate the various actors engaged in a hazardous activity (e.g. the active phase of a deep geological disposal) around a common overriding goal of safety. Usual definitions of safety culture essentially focus on a given organisation (e.g. energy company, regulator, TSO), its management, policies and practices[1]. However, in current times characterized by the development of horizontal exchanges and networks, multiple subcontracting, multi-level governance schemes, and increasingly complex interactions going through and beyond the limits of formal organisations and including non-institutional actors (NGOs, independent experts, …), a more systemic view on safety culture seems necessary. These new views on safety culture should balance two requirements for complexity management over several generations: the necessary differentiation of roles and the necessity to set up 'transboundary conversations' [5] to avoid obsolescence of the safety management system and favour the necessary transversality between specialised scientific and technical compartments on the one hand and between these compartments and society.

A generic definition of safety culture based on the performed literature review has been proposed by SITEX-II project as "a set of norms, attitudes, roles, and social and technical practices that a particular group of people share with respect to safety" [6]. Further, each of the interviewees has suggested his own definition based on the proposed generic definition. Despite some differences, a universal rationale can be converged towards '…a common set of values, principles and references governing safety…'. The performed analyses led further to the investigation what could be a shared safety culture between institutional actors (regulators, TSOs) and non-institutional actors (independent experts, NGOs).

The interviews showed that for all interested parties safety culture is crucial to ensure the adequate importance to safety. And therefore some basic issues of safety culture (e.g. priority given to safety) has acquired a transversal dimension binding all interested parties notwithstanding that some differences in delineating of safety culture can exist specific to the group considered (institutional, NGO, group of citizens, …).

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[1] IAEA INSAG 4 report thus defines safety culture as "that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance."

Notoriously, up to now, safety culture was mainly developed at the corporate level within institutional organisations (Regulatory Bodies, TSOs, implementers, …) according to the international recommendations [7] . During the workshops, it appeared that some elements of this *'corporate safety culture'* (namely, principles of optimization imposing to consider different options based on safety issues and to balance them, defence-in-depth requiring different levels of protection, …) are also shared by the other interested parties.

The discussion held during the project showed that it has to be recognized that there is no necessity for non-institutional civil society and institutional groups to share '*corporate safety culture'* as a whole, however there is a need to identify elements of a '*societal safety culture*' (set of values, references, through which the different actors of the society can have assess together the degree of assurance that the safety objective is reached), which can be shared in order to achieve an effective collaboration along the decision-making process among the different parties organised around a common good of safety of radioactive waste management.

The results of the performed analyses show that while corporate safety culture and societal safety culture have a right to exist separately, the need to identify the elements that can be shared by both institutional and non-institutional actors, to assess together that the safety objective is reached, has become an important tool towards improvement of the public engagement process.

Conditions for constructive engagement of the non-institutional actors along the safety case review of the geological disposal facilities

One of the main requirements for constructive engagement of non-institutional actors and effective interactions between the interested parties driven by the consideration of safety as a common good is that civil society must take part in the decision making process from its inception. Types of interactions can vary depending on the considered stage of the decision making process. Additionally the nature of the public engagement process should carry a deliberative character. Participants expect to be given sufficient time to consider and to discuss an issue in depth before they come to a considered view. The representatives of the non-institutional focus group underline that the experience has shown that public trust very quickly disappears if participants feel that they are being pushed in a particular direction. This trust should not be considered as a condition for the acceptance of a particular technical solution (like deep geological disposal, for example) but as a condition for managing high complexity as shown by Luhmann's works [4]. The principles of the deliberative public engagement should rely on the transparency and integrity of the engagement process itself, respect of the participants, effective two-ways dialogue and assessment what has been achieved to review future practice.

With the help of the questionnaire, personal interviews and a number of civil society workshops, several fundamental conditions for public engagement have been pointed out. They are: transparency (transparency of information, decision- making process, transparent reporting of participants' views) and access to information, to justice, to resources and to expertise. The participants of the project underline that the principles of effective transparency should be incorporated in all aspects and stages of communication on the radioactive waste management issues, as recommended in [8]. Access to information is one of the crucial points in the process of public engagement. Civil society expects access to requested information will be timely. One of the recommendation states that legal implementation of access to information can become effective only if a culture of openness to information collection and dissemination in the field of radioactive waste management is developed. One requirement is to underpin and ensure effective access to information and dynamic public participation as well as to guarantee that civil society input is taken into account which may impact on decisions taken. One must not forget, that the scientific and technical aspects of the radioactive waste management are complex and therefore access to resources (namely funding) and access to expertise are important to achieve enduring and constructive engagement from the side of civil society. Resources play also a fundamental role in access to expertise and to a possibility to carry out an independent research if necessary. A broad public education can undoubtedly improve the interactions between the interested parties and more importantly the quality of the decision- making process and therefore it is incumbent upon the institutional expert groups to provide enough information for the interested groups of non-institutional actors to pave the way towards effective civil society engagement and collaboration. There are a variety of ways this can be achieved. For example, that contributions from civil society organisations such as Nuclear Transparency Watch (a European NGO) [9] proposed a Web Portal to furthering public understanding of Radioactive Waste Management.

CONCLUSIONS

In this article, the results of the SITEX-II project related to the improving the interactions with civil society along the safety case review process of radioactive waste management are presented. The questions of safety culture and effective public participation have been investigated.

A broader concept of safety culture that includes both the aspects of corporate and societal understanding of safety culture has been proposed. The discussion held during the project showed that it has to be recognized that there is no necessity for non-institutional civil society and institutional groups to share operational safety culture as a whole, however there is a need to identify elements, which can be shared (namely principles of optimization, defence-in-depth) at the societal level. As a result, shared safety culture has been recognised as a means to achieve collaboration powerful engagement among the different parties.

Conditions and means to involve civil society along the decision-making process are also identified. One of the main requirements is that civil society must take part in the decision making process from its inception. The nature of the public engagement process should carry a deliberative character. Participants expect to be given sufficient time to consider and to discuss an issue in depth before they come to a considered view. Several fundamental conditions for public engagement have been pointed out, namely transparency and access to information, to justice, to resources and to expertise.

Although the qualitative nature of the methodology and the relatively limited number of interviews performed were not meant to be fully representative for the interested parties, the conclusions drawn based on the analysis of the questionnaire provide a comprehensive picture of the expectations of different actors of civil society in terms of conditions for interactions along the safety case review process. Better understanding of the current situation in the area of radioactive waste management leads to highlighting future milestones towards the improvement of decision-making processes, sharing of common elements of safety culture between institutional and non-institutional actors, and the reinforcement of the participation of civil society in a long-lasting perspective necessary to achieve broad intergenerational trust.

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The Swedish Radioactive Waste Management: Communication about the known and unknown

Nele WULF
ITAS, Karlsruhe Institute of Technology
nele.wulf@kit.edu

At this conference I would like to present the current state of my dissertation: My thesis is concerned with the development of the Swedish radioactive waste management concept (KBS-3) and the interplay of different actors and their knowledge perspectives. A focus is put on how the actors speak about uncertainties and the unknown while they reflect on the need to come to a decision.

The management of radioactive waste is in and of itself one of the human endeavors that would take the longest to complete, as the waste has to be safe for about one million years. Already the copper canisters Sweden wants to build to be one of the barriers that shield the environment from the waste have to be safe for about 100,000 years. Therefore the search for a site that could hold a final repository for spent fuel presents itself as a great challenge to many modern societies. The Swedish concept was developed by the waste management company SKB (Svensk Kärnbränslehantering Aktiebolag) which was founded by the nuclear industry. SKB submitted an application for the concept at the Forsmark site in March 2011. The application is still in the review process.

Various different actors are part of this process and are communicating to solve the problem at hand. Their communication includes the exchange of different kinds of knowledge concerning this complex endeavor. The complexity of dealing with radioactive waste results in diverging assessments, results and interpretations that for the longest time would have been considered by scientists and others as something we do not know *yet*. Today such aspects are more and more viewed as potentially not knowable or not able to clarify finally. The unknown comes into view.

My work is situated in this context and takes a closer look at how Swedish stakeholders deal with the unknown. I am analyzing interviews with those involved in the development of the KBS-3 concept. Such stakeholders include persons from the nuclear industry, NGOs, the municipalities that were or are prospective sites for a final repository and others. When speaking about the development of KBS-3 the different actors include their perspectives on the knowledge that is available to them and also on uncertainties and the unknown – which might be an inevitable part of radioactive waste management – and by that frame them in different ways (cf. Wehling/Böschen 2015).

According to Gotthard Bechmann and Nico Stehr dealing with what we do not know is the most important variable when it comes to decision-making. Since we cannot know the future it is all the more important how the unknown is processed in our decision-making (cf. Bechmann/Stehr 2000:120). Looking at the different framings of uncertainties and unknown aspects by the interviewed actors it is most interesting how they argue the possibility when and how to decide on the final repository concept KBS-3 and to find out, if one could make out different cultures of dealing with knowledge and its absence.

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BIOGRAPHY

Studies of sociology with a minor in sinology (B.A.) and postgraduate studies of sociology (M.A.) at University of Freiburg, Germany. Graduation in 2014. Since September of 2014, doctoral student at ITAS (The Institute for Technology Assessment and Systems Analysis) at KIT (Karlsruhe Institute of Technology). Member of research project ENTRIA, which is founded by the German government and is concerned with finding disposal options for high-level (heat generating) radioactive waste and does interdisciplinary analyses and development of evaluation principles.

DIALOGUE SESSIONS

Confidence and trust in long lasting perspectives – 1

Chair: Pierre-Benoît Joly

Pierre-Benoit Joly, economist and sociologist, is Directeur de recherche at the National Institute of Agronomic Research (INRA) and lecturer at the Ecole des Hautes Etudes en Sciences Sociales (EHESS). He has been the Director of the IFRIS (French Institute for Studies of Research and Innovation in Society) and is now the director of LISIS (Laboratoire Interdisciplinaire Sciences Innovations Sociétés). His research is focused on the study of co-production of knowledge and social order. He has been member of the EU expert group « Science and governance » and of the working group of the European Science Foundation « Science in Society », awarded with the Ziman Price of the European Association for the Studies of Science and Technology (EASST).

Professor Bernd Grambow, Ecole des Mines de Nantes, holds the Chair on nuclear waste disposal and is head of the Subatech laboratory. Professor Grambow is the former director of the national CNRS-academic/industrial research network NEEDS (nuclear: environment, energy, waste, society). His areas of scientific expertise are radiochemistry, nuclear waste disposal science, geochemical modeling, radionuclide migration in the environment, chemical thermodynamics, and dynamics of solid/liquid interfaces.

Ms. Saida Laârouchi Engström is the VicePresident of Strategy and Programs at SKB. She has a background in chemical engineering and started her career in the Swedish Nuclear Inspectorate as a safety inspector of nuclear installations in Sweden. After 11 years, she joined SKB, first as a leader for feasibility studies to select a site for a final repository for spent fuel in Sweden. Under the site investigation project, Ms. Laârouchi Engström was in charge of the environmental assessment studies and licensing. Ms. Laârouchi Engström has been and still is in charge of the dialogue between SKB and all the stakeholders in Swedish society.

Dr. Allison M. Macfarlane is currently Professor of Science and Technology Policy at George Washington University and Director of the Center for International Science and Technology Policy at the University's Elliott School of International Affairs. She recently served on the Blue Ribbon Commission on America's Nuclear Future (2010-2012), and as Chairman of the U.S. Nuclear Regulatory Commission (2012-2014). Dr. Macfarlane holds a PhD in geology from the Massachusetts Institute of Technology and a BSc degree in geology from the University of Rochester. In 2006, MIT Press published a book she co-edited, *Uncertainty Underground: Yucca Mountain and the Nation's High-Level Nuclear Waste*.

Frédéric Plas holds an engineer degree and a higher education diploma in mechanics and hydraulics from the Ecole Nationale Supérieure of Applied Geology of Nancy. Mr. Plas began his career at the CEA, before joining Andra in the 1990s, where he occupied various managing positions in the Scientific Division. In particular, he managed the services in charge of integrating scientific data, describing the behavior of a disposal facility over time, and of quantitatively and qualitatively evaluating the performance and the safety of the disposal facility, primarily through numerical simulation. He is currently Director of the Research and Development Division of Andra since 2013.

DIALOGUE SESSIONS

Confidence and trust in long lasting perspectives – 2

Chair: Soraya Boudia

Soraya Boudia, is historian and sociologist of science and technology, professor at University Paris Descartes. Her work explores the role of science and technology in politics and policy particularly the transnational government of health and environmental risks. She serves as deputy director of Center for research in medicine, science, health, mental health, and society (CERMES3) and she is a member of scientific council of the French Agency for Food, Environmental and Occupational Health & Safety (ANSES).

Peter Galison is the Joseph Pellegrino University Professor of the History of Science and of Physics at Harvard University; Galison's work explores the complex interaction between the three principal subcultures of physics--experimentation, instrumentation, and theory. He is also greatly concerned with the impact of technology on the self, and how this influences science, policy, and development. With Robb Moss, he directed "Secrecy" (2008, 81 minutes) and recently completed "Containment" (2015, premiered at Full Frame), about the need to guard radioactive materials for the 10,000 year future.

Patrick Landais is an engineer in geosciences and holds a doctorate in geochemistry. After working for Elf-Aquitaine and Cogema, he was Research Director at CNRS, scientific Director and R&D Director of ANDRA, and Scientific Director of the French geological survey (BRGM). For his studies on the feasibility of geological disposal, he received in 2013 the Grand Prix Dolomieu of the French Academy of Sciences. He is a member of several scientific committees and Knight in the National Order of Merit. In 2016 he returns to ANDRA as Chief Technology Officer where he is now in charge of development, innovation and knowledge management.

Dr. Allison M. Macfarlane is currently Professor of Science and Technology Policy at George Washington University and Director of the Center for International Science and Technology Policy at the University's Elliott School of International Affairs. She recently served on the Blue Ribbon Commission on America's Nuclear Future (2010-2012), and as Chairman of the U.S. Nuclear Regulatory Commission (2012-2014). Dr. Macfarlane holds a PhD in geology from the Massachusetts Institute of Technology and a BSc degree in geology from the University of Rochester. In 2006, MIT Press published a book she co-edited, *Uncertainty Underground: Yucca Mountain and the Nation's High-Level Nuclear Waste*.

Dominique Pestre is a professor at the École des haute études en sciences sociales in Paris. His research focuses on the history of scientific and technological practices and, more broadly, on the social and political history of science. He has written about science and knowledge production in the West, and especially about the Cold War and the neoliberal turn of the last decades. Trained as a physicist, he is also the author of several publications on the history of physics in twentieth-century France, co-author of a history of the European center for nuclear research, and Editorial Director of the three volume "Histoire des sciences et des savoirs" achieved in 2016.

FRENCH NATIONAL RADIOACTIVE WASTE MANAGEMENT AGENCY

1-7, rue Jean-Monnet
92298 Châtenay-Malabry cedex - France

www.andra.fr