LISIS Laboratoire Interdisciplinaire Sciences Innovations Sociétés

INRA SCIENCE & IMPACT

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

UPEM UNIVERSITÉ PARIS-EST MARNE-LA-VALLÉE

INTERNATIONAL CONFERENCE

Governing by Prediction? Models, data and algorithms in and for governance

Paris, Musée des Arts et Métiers, 11-13 September 2017

Abstracts

Keynote lectures

Claudia Aradau, King's College London: "Governing others: Anomaly and the algorithmic subject of security"

As digital technologies and algorithmic rationalities have increasingly reconfigured security practices, critical scholars have drawn attention to their performative effects on the temporality of law, notions of rights, and understandings of subjectivity. This article proposes to explore how the 'other' is made knowable in massive amounts of data and how the boundary between self and other is drawn algorithmically. It argues that algorithmic security practices and Big Data predictive technologies have transformed self/other relations. Rather than the enemy or the risky abnormal, the 'other' is algorithmically produced as an anomaly. Although anomaly has been often used interchangeably with abnormality and pathology, a brief genealogical reading of the concept shows that it works as a supplementary term, which reconfigures the dichotomies of normality/abnormality, friend/enemy, and identity/difference. By engaging with key practices of anomaly detection by intelligence and security agencies, the article analyses the materialisation of anomalies as specific spatial 'dots', temporal 'spikes' and topological 'nodes'. We argue that anomaly is not simply indicative of more heterogeneous modes of othering in times of Big Data, but represents a mutation in the logics of security that challenge our extant analytical and critical vocabularies.

Paul Edwards, William Perry Fellow, Stanford University and Professor, University of Michigan: "Knowledge Infrastructures under Siege: Environmental Data Systems as Memory, Truce, and Target"

This talk examines the history of environmental data systems in the context of the Trump administration's brutal assault on climate science in the USA. Data analysis models — aka algorithms — are as important as "raw" data in generating knowledge of Earth's climate. Yet they are also easy political targets. From an earlier focus on critiques of climate simulation models, since about 2000 climate denialism has shifted toward attacks on data and data models. This movement recently reached a crescendo, with the ascendancy of climate change deniers to dominant positions in the United States, Canada, Australia, and elsewhere. The shift is associated with new media environments that effectively created a "glass laboratory," where even scientists' emails became metadata in the public life of climate knowledge. In this situation, where previously settled norms and standards have become targets for wholesale elimination, data studies must balance the necessity of critique with its potentially destructive consequences.

Stephen Hilgartner, Cornell University: "Building Knowledge: Models, Predictions, Credibility, and Sociotechnical Change"

This talk concerns the use of predictive technologies by actors who self-consciously seek to deploy them to remake knowledge about risk in ways that will transform public policy, markets, and sociotechnical practices. As an empirical case, I examine knowledge production concerning strategies to mitigate the physical and financial risks of damage to low-rise buildings from "extreme weather events," such as hurricanes, hailstorms, and wildfires. Damage from hurricanes in the U.S. now can run into the tens of billions of dollars, and sometimes much more, as well as causing substantial loss of life. (Hurricane Katrina cost an estimated $108 billion and led to more than 1,800 deaths.) The analysis focuses on an institute, funded by property and casualty insurance companies, that seeks to "do for buildings what the crash test people did for cars." Research in this domain involves a variety of physical and computational models intended to make damage to buildings more predictable and to design and test strategies for mitigating it. The diverse actors who operate in this arena include climate and weather analysts, wind engineers, insurance risk modelers, manufacturers of building components, real estate developers and builders, government officials responsible for building codes, emergency managers, and the owners of homes and other real estate. Drawing on ethnographic and interview data, I analyze the entanglement of different kinds of models and data, the work necessary to produce credible predictions, the staging of visual displays, the interplay of past experience and future prediction, and the challenges of inspiring uptake and instituting change. The analysis highlights some complexities of governance by prediction.

Paper abstracts

Stefan C. Aykut, University of Hamburg: "Reassembling energy policy. Models, forecasts, and policy change in Germany and France"

Ongoing debates about the need to deeply transform energy systems worldwide in response to ecological, economic and geopolitical concerns, have spurred renewed scholarly interest in the role of future-visions and foreknowledge in energy policy. Forecasts and scenarios are in fact ubiquitous in energy debates: commonly calculated using energy models, they are employed by governments, administrations and civil society actors to identify problems, choose between potential solutions, and justify specific forms of political intervention. But such "foreknowledge" has an ambiguous status. It rests on empirical observations (often derived from statistical series), projections concerning key variables like population and economic growth, production patterns, prices and energy technologies, and includes assumptions about the relationship between these variables as well as their links to energy production and consumption. In contrast to other forms of knowledge, claims to objectivity of foreknowledge are circumscribed by the complexity of social processes and a range of 'if-then' assumptions that characterise the model-world. Consequently, early scholarly debates concentrated on the 'knowability' of the future (Polak, 1973), the ways in which such futures are 'constructed' (Raimond, 1996) and shape the cultural context of knowledge production (Wynne, 1984, Thompson, 1984, Baumgartner and Midttun, 1987). More recent research has focused on the wider social and cultural setting in which such futures are embedded (Jameson, 2005, Hastrup and Skrydstrup, 2012, Appadurai, 2013, Andersson and Rindzevičiūtė, 2015), and analysed the ways in which they affect policy-making and governance (Garb et al., 2008, Pulver and VanDeveer, 2009, Grunwald, 2011, Dieckhoff, 2014), as well as social interactions (Callon, 2007, MacKenzie et al., 2007).

A central theme in this literature has been to show how dominant models reproduce dominant worldviews and stabilise social order (Wynne, 1984, Shackley and Wynne, 1996, Callon, 1998, Edwards, 2010), while alternative models and their effects receive less attention (for an exception, see Henriksen, 2013). Accordingly, the presentation aims to complement the existing literature through reflection on the transformative role of *changing* modelling and forecasting practices. It presents a historic study of foreknowledge-making – modelling, forecasting, and scenario-building – and its relationship to the structuring of 'energy policy' as an autonomous policy domain in France and Germany. The main argument is that new ways of assembling energy systems and policy worlds in models and energy futures may, under certain conditions, enable the emergence of new political constellations and the enactment of new forms of political intervention. To understand such processes of change, however, it is not sufficient to look at modelling practices alone; instead, it is necessary to take into account the 'predictive arrangements' (Schubert, 2015) – such as policy networks in scenario-building and forecasting exercises – in which models are embedded.

To lay out this argument, I combine two strands of research. The first is work in the anthropology of politics that has reconceptualised policy-making through a focus on 'policy assemblages' – i.e., loosely coupled and more or less stable constellations of discourses, practices, human bodies and material artefacts, in which specific forms of governing are 'enacted' (McCann and Ward, 2012, Clarke et al., 2015). The second is recent research in science and technology studies (STS) exploring the 'performative' effects of foreknowledge on social practice and politics. The focus of the presentation is not on modelling or forecasting techniques per se, but on the ways in which such techniques intervene in public debate and social practice, and form part of technologies of government. I thereby distinguish between three dimensions of performativity: 'discursive performativity', which acts on the level of discourses, beliefs and expectations (Merton, 1948, Van Lente and Rip, 1998); 'material performativity', which points to practices and material artefacts that 'equip' social interactions (Callon, 1998, Mackenzie, 2006); and 'social performativity' (Schubert, 2015), which describes how forecasting or scenario-building exercises organise social spaces and structure actor networks.

Empirically, the presentation builds on a historical study on energy modelling and forecasting in German and French energy policy, based on extensive document review, archival research, and 30 semi-structured interviews with energy modellers as well as administrative and political end-users of modelling results. To analyse the conditions under which policy change occurs, the presentation focuses on two periods: the making of national energy policies as 'energy supply policies' in the post-war decades; and challenges to dominant approaches to energy policy and energy modelling in the 1970s and 1980s.

It shows that the emergence of energy modelling and forecasting is intimately related to the institutionalisation of 'energy policy' as a new policy field, and that both – predictive practices and policy-making – have evolved in close interaction ever since. In both countries, social and political events in different periods triggered innovations in modelling, which required the production of new data. This in in turn contributed to transforming problem definitions, induced or accompanied changes in energy policy, and helped to sustain novel institutions. The way energy forecasts relate to energy policy, however, has differed in the two countries, and this relationship has changed over time.

In the first period, forecasting exercises in France were traditionally carried out by the national planning bureau Commissariat general au Plan, and their status was not only epistemic, but also explicitly political. Although forecasting associated major actors in the energy field, it was characterised by an inherent asymmetry: estimations of electricity demand were almost exclusively calculated by EDF's models, and matched the company's industrial strategy. When model predictions and real-world developments diverged in the 1970s, the dominant policy assemblage enacted a policy of household electrification that re-calibrated the electricity-intensity of economic development to a level compatible with the country's ambitious nuclear program. In Germany, national energy forecasts emerged in a context of crisis in the coal sector, which challenged the role of the federal state in energy policy. A parliamentary *Energie-Enquête* commission was created in response. It introduced innovations in modelling techniques that made visible substitution processes in economic sectors, and called for federal government to take a more proactive role. Progressively institutionalised in the preparation and evaluation of federal policies, the modelling approach envisioned energy policy as a choice between different energy carriers, and furthered the emergence of new dominant framings such as the 'coal priority' and 'CoCoNuke' (Conservation, Coal, Nuclear) policies.

In both countries, established forecasting practices and the 'predictive arrangements' in which they were embedded were challenged by new actor coalitions in the 1970s. A situation where forecasts were more or less directly embedded in policy-making and models established by experts close to the dominant policy assemblages gave way to a new configuration, characterised by a multiplication of model-types and a politicisation of forecasts, which were produced and taken up by a wide range of actors in an increasingly controversial debate. But while alternative scenarios succeeded in reassembling German energy policy along lines that were conductive to policy change, this did not occur in France, where demand-side modelling was institutionalised in state administrations, but failed to enrol potential agents of a new political constellation.

Common attempts to explain this rigidity of French energy policy point to the homogeneity of the dominant actor-coalition and the heavy investments made by EDF (e.g. Puiseux, 1987: 195). A focus on predictive practices adds two important elements to the puzzle: first, while bottom-up models did provide a powerful tool to counter dominant discourse, and formed the quantitative backbone for demand-reduction policies in public discourse and inter-ministerial negotiations, they did not deliver a coherent future vision in which major actors of French energy and industrial policy could recognize or project themselves. As for the ALTER scenario, an alternative modelling and scenario-building endeavour by anti-nuclear activists, its architecture proved too uncompromising to offer such actors – 'progressive' industrialists, entrepreneurs or municipalities – a plausible and desirable future in which their expertise and activities would be valued.

In Germany, by contrast, the *Energiewende* scenario produced by the newly founded independent research centre *Öko-Institut* not only 'equipped' the ecological movement with new arguments in its battle for a non-nuclear future; it also 'reassembled' energy policy in a way that opened up energy debates. Öko-Institut's vision functioned as a 'prospective structure' (Van Lente and Rip, 1998), proposing both a new narrative and a new arrangement of the energy policy world that could subsequently be enacted. This was accompanied by a formalisation of bottom-up models at Öko-Institut and other modelling centres. These models were increasingly used in policy-making and administrative practice and contributed to durably anchoring efficiency and renewables policies in policy circles.

Finally, a symmetrical, yet opposite evolution in the 1980s increased the discrepancy between the energy trajectories of the two countries: while the established French 'predictive arrangement' around Commissariat general au Plan progressively lost its central position, making it more difficult to recompose French energy policy around an alternative, negotiated future vision, parliamentary Enquete Commissions progressively emerged in Germany as a new locus of future-making that exerted a lasting influence on energy debates. The scenario technique introduced by these commissions (first in a 1979 commission on nuclear energy) also durably changed official forecasting practices: it institutionalised a means of enabling dialogue in a controversial environment, and was instrumental in organising energy discourse around a set of distinct, mutually exclusive future-visions, which roughly corresponded to existing and emergent policy assemblages. The lasting influence of the *Energiewende* report can therefore only be understood by combining the three dimensions of performativity identified above: it proposed a new ontology which re-structured energy discourse; its modelling approach was taken up in administrative and civil society practice; and its vision was progressively enacted by a ‘predictive arrangement’ that contributed to the formation of a new policy assemblage.

Accordingly, I conclude by arguing that further research should not only focus on the effects of foreknowledge on expectations and beliefs (‘discursive performativity’), but also take into account how new models ‘equip’ political, administrative and market actors (‘material performativity’), and how forecasting practices recompose and shape wider policy worlds (‘social performativity’).

Bilel Benbouzid, Université Paris-Est Marne-la-Vallée, LISIS: « An Inquiry into Predictive Policing : Science, Organization and Law »

This presentation deals with predictive policing in the United States, the development of predictive platform that mine "data on the times, locations and nature of past crimes, to provide insight to police strategists concerning where, and at what times, police patrols should patrol, or maintain a presence, in order to make the best use of resources or to have the greatest chance of deterring or preventing future crimes" (Wikipedia: "Predictive Policing"). Firstly [science], we will test the algorithm of PredPol, Inc. against an original social critique.

PredPol is a company that offers a predictive information service (in the form of Software As A Service) based on an algorithm inspired by earthquake prediction methods. As the researchers in this startup declare that their algorithm is inspired by an algorithm used in seismology, and given that for commercial reasons the company refuses to provide access to its algorithm, a promising alternative is to directly consult the seismologists who developed and use this algorithm. The research that influenced PredPol is that of David Marsan, a professor in the earth science laboratory at the University of Savoie, in Chambéry, France, and a specialist in the study of earthquake aftershocks. It is the algorithm that he developed that was introduced into the PredPol system, on the basis of the principle that crimes are subject to "after-crimes" in the same way as earthquakes are followed by aftershocks. With his help, we were able to manipulate the PredPol algorithm, exploring its application to open access crime data from the city of Chicago (which were also used by PredPol researchers). We will show how the approaches of the seismologist and PredPol researchers diverge. We find that two different ways of dealing with "aftershocks" emerge, even though both feature the same algorithm and the same data. This little experiment reveals two modes of moral reasoning: exactitude versus precision. Secondly [organisation], we will show how the practice of predictive policing emerged as an alternative to the practices of Compstat, a New Public Management (NPM) tool. While the management techniques of the 1990s *evaluated* the work of police officers (through the metric of stop and frisk quotas), machine learning algorithms enable optimization of the public supply of daily security, assigning a quantified value to security (an optimal distribution of daily monitoring and intervention).

Policing algorithms enable a controlled dosing of security. Predictive analysis algorithms are not machines for anticipating crime, but machines for the valuation of the possibility of police action (Dussauge, Helgesson, and Lee 2015). It is the content of this *valuation* – its moral economy – that we will attempt to describe by comparing two different programs – Predpol and Hunchlab. The last part of the presentation [law] will analyse legal debates on the principles regulating predictive policing in the jurisprudential context associated to the Fourth Amendment, which sets out the principles for the legality of state intrusion in the lives of individuals. To what extent can police action be justified by the recommendation of an algorithm? We will attempt to understand why jurists believe that the existing standards requiring police to have good reasons for belief ("probable cause" and "reasonable suspicion") cannot provide a legal framework for automated algorithmic decision making. These principles can neither prohibit nor authorize those decisions. We will show that only a law and economics approach, combined with principles of fairness and distribution of intrusion between groups, can provide a solution to this problem. There can be a legal critique of machine learning, but it must provide a quantifiable regulatory principle. In the trial of predictive policing, which we reconstruct here using exchanges between legal scholars, jurists seek the legal measure that existing jurisprudence does not prevent from being quantified. While the hit rate of machines is not an acceptable reference (jurisprudence rules out the use of mathematical definition of "probable cause" or "reasonable suspicion"), the “hassle rate” that machines produce have emerged as a legitimate basis. Predictive policing succeeded in passing tests of its legality through this solution based on the *valuation* of the social cost of false positives. The difficulty facing legal criticism in this context is that the legality of police intrusion no longer depends only on the absolute and intangible principles of the Fourth Amendment, but also on the use of technical and practical points of view as legal tools of government. From these three perspectives, we will extract the value in tension when predictive algorithms cross the modes of existence of science, organisation and Law.

Henri Boullier, CERMES3 & IFRIS, David Demortain, INRA and LISIS: "The economy of predictive knowledge: software tools to predict chemicals risk in REACH"

How does one way of predicting come to be dominant over other, alternative proposals? How do ways of predicting take shape in a contentious field? Our talk is the result of a study of software tools used for chemical control, to predict the toxicity of chemical substances for regulatory purposes. In the context of a massive market like that of industrial chemicals, which counts dozens of thousands of products on the market, modeling is a way to produce some data on their properties at a lower cost. In the case that we have studied, that of the REACH regulation, companies must share data on about 30 000 chemicals. Figures show that generating data to comply with this legislation will cost €8.8 billion using today's" testing methods (Hartung, 2009). To avoid the use of animals for testing, but also to limit their costs, companies can now choose among a wide spectrum of software tools that can predict the toxicity of their products.

Among these tools however, a few have become dominant. In the past 15 years, prediction has been used more and more frequently but there has been a more towards the most qualitative forms of modeling. Today, one of the most widely used tool uses an approach that mimics the way toxicologists work, and that, at the same time, leaves them "in charge". The dominance of such qualitative approaches is all the more surprising that most of the software tools developed since the 1960s were statistical models that promised that, eventually, they would be able to predict the toxicity of almost any chemical. The argument that we're making is that these tools are part of an "economy" of predictive knowledge, a network of relations between actors that contend about and constantly put to trial predictions and the methods they rest on. The objective of this talk is to recount the relative disenchantment of users for statistical methods, the success of the OECD toolbox, mostly based on qualitative reasoning, and analyze the "economy of predictive knowledge" these stories can help define.

Our talk starts with a brief presentation of the different paths of prediction. In the context that we are interested in, prediction is a tool for regulation, and, as such, constitutes a way of knowing things that defines how they should be regulated. This use of prediction has become widespread. The Federal Aviation Administration uses modeling of their design to regulate aircrafts. The marketing authorizations of pharmaceutical products are also based on prediction of the effects of impurities. In the regulation of industrial chemicals, chemicals have to be registered by companies. The modeling of their properties and toxicity is a way to produce data on chemicals that are poorly documented. But even when prediction is specifically used for regulation, several ways of predicting can be developed. For chemicals, the different approaches to prediction include statistical methods, molecular modeling, expert systems, analogue approaches, quantum mechanics, machine learning or derived on an empirical basis (Marchant, 2011).

To understand how the different ways of predicting complement, and compete with, each other, we briefly retrace their history. Historically, toxicity prediction tools were usually put together by academics, became commercial products (sometimes very expensive ones) that targeted the pharmaceutical industry. In the beginning, these were rather based on statistical modeling. This is the case with QSAR systems like Topkat, which was a tool for predicting the toxicity of molecules in the context of drug development. Other tools like DEREK function with rules derived from human expert knowledge. The Environmental Protection Agency made yet an other choice, that of mixing approaches and formulating "modest" promises. Their EPI Suite includes at the same time statistical and qualitative approaches, while always reminding the users that "screening-level" tool and that it "should not be used if acceptable measured values are available".

Although the landscape of tools seemed more or less stabilized in the late 1990s, two elements forced some changes. First, the multiplication of tools used for regulatory purposes caused academics and regulatory agencies to compare their proposals and assess their predictions. These evaluations showed that, for some of them, predictions weak in many cases. Only for some basic endpoints could they be really trusted. The second element was the REACH project. Its article 13 would promote the use of alternatives to animal testing, and yet the tools on the market were either very specific to some chemical families, used approaches too radically different from that of "traditional" toxicology or tended to black-box their scientific reasoning.

In this context of relative disenchantment and of legal change, the OECD develops a computer program that can be used in the context of REACH. Their idea of a "QSAR database" becomes the basis for developing what starts to be called a "QSAR application toolbox", meaning a computer program that could be used for free by companies and public authorities. Fairly quickly though, the shift of the toolbox from statistical approaches towards read-across becomes visible. The main reason is the disadvantages of QSAR models: they require a lot of validation work, their predictivity/efficiency are still not very high and their applicability domains are often unclear. Just like the tools developed at the EPA in the 1980s-1990s, the toolbox makes the "modest" promise of producing basic information for which the validation levels are rather high, while at the same time leaving the toxicologists in charge.

The paper documents the series of collective trials by which the failure of statistical prediction as a method emerged in the field of chemical regulation, leaving the field open for the development of analogies- or read-across based methods. Ultimately, it demonstrates how a form of knowledge and epistemic culture, prediction of toxicity, is defined in an economy, meaning a network of relations between actors giving shape to the market of chemicals, who contend about and constantly put to trial predictions and the methods they rest on. This political economy is mainly structured by the negotiations between commercial and institutional actors, or regulated and regulatory actors, mediated by the action of a network of scientists who, by circulating the products of their own predictions and evaluations of models, construct the benchmark of predictive knowledge for regulation, around which this economy started, slowly, to revolve.

Dominique Cardon, Sciences Po. and Medialab: "Personalized prediction and machine learning methods in tools for web computation"

One of the main characteristics of the modes of computation known as big data concern the generalization of machine learning methods. They offer to calculate the society in a way that do not match the requirements of centrality, univocity and generality of statistical methods, plotting individuals around a statistical mean. Techniques of personalized prediction do away with any form of totalization in the representation of society. They break with traditional statistical methods. They do not aim to produce a central measure embracing all individual situations, but to measure from every situation a personalized totality. They do not manufacture a univocal representation, but a modular one, that varies depending on individual positions. They do not aim to produce a shared generality overcoming all statistical individuals, but for more localized truths[1]. They claim for themselves a new capacity to produce personalized predictions.

As the historiography of statistics has shown, the deployment of these vast apparatuses to quantify societies emerged hand in hand with the probabilistic understanding that if social phenomena were not ruled deterministically, it was nevertheless possible to interpret society based on observable regularities[2]. As Ian Hacking has shown, the development of statistics can not be disconnected from the rise of democratic, liberal societies, whereby individual freedom and autonomy is compensated, for institutions seeking to govern societies, by the production of objectively derived regularities[3].

The probabilistic paradigm thus replaced natural laws and their inherent causalism, offering a technique of uncertainty reduction which, by the end of the vast program of classification and categorization of populations, produced an image of the distribution and regularities of more or less statistically normal behaviours. The vast enterprise of recording, quantification and measure of society that unrolled in the XIXth century, thus allowed establishing the credibility of social statistics, and overall trust in numbers.[4]

Practically speaking, the investment in and maintenance of a codified system of regular recording, and epistemologically speaking, the distribution of statistical occurrences around mean values, the frequentist method in social statistics thus contributed to make "constant causes" more robust. Embedded in institutional and technical apparatuses, they acquired a kind of exteriority. They became the trusted basis on which one could establish correlations about nearly any social phenomenon, and infer causes too.

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Now, it is a different method and model, that of the probability of causes, that so-called Bayesian techniques, long marginalized in the history of statistical methods, offer to re-open, making it possible again that "accidental" rather than "constant" causes, become the basis of new sorts of statistical inferences.

To broadly characterize the historical turn that is occurring with the advent of this now mode of statistical reasoning, one could say that it replaces the normal distribution by the "empty matrix" [5]. In digitized environments, the proliferation of data recordings lead to a massive increase in the number of variables that are available for computation. Even if matrices within which those variables are computed remain empty, calculations continue to follow the notion that, in certain contexts, rare and improbable variables may have some effect on some correlations. This paradigm thus revives inductive techniques of data analysis, and avoids engaging in the reduction and stabilization of the space of relevant variables. Causes thus become inconstant, and get combined by the computer in changing ways, depending on the local objectives imposed by the various users that seek to predict their environment. This shift towards personalized prediction implies that the causes of individual behaviors become much more uncertain. The recording of multiple, disparate behaviors may, in certain circumstances, depending on the context, produce a causality that is sufficient to explain, in a relevant manner, the acts of individuals.

[5] A phrase that statisticians of big data use to underline the fact that they have at their disposal many variables in column, and statistical events per line, but very few statistical events to actually inform each variable overall.

Christophe Cassen, CNRS-CIRED, Béatrice Cointe, LAMES and Alain Nadaï, CNRS-CIRED: "Organizing policy relevant Expertise on Climate Action: the Community of Integrating Assessment Modelling"

International climate negotiations are informed, and to an extent framed, by an array of numerical projections and scenarios produced using different types of models that help to reduce the complexity and heterogeneity of relevant processes and interactions. This paper characterises the production of one specific type of "foreknowledge" about the possible evolutions of drivers of climate change and about mitigation strategies. This paper looks more precisely at the production of emission scenarios for the "Working Group III" on mitigation of climate change for the IPCC AR5 and asks what scientific and institutional apparatus was set up to carry it out. It describes how the production was delegated to a specific research collective that also relied on this exercise to define itself and its boundaries and to establish itself as a potential epistemic community.

At the core of the research collective are Integrated Assessment Models (IAMs) which are stylized numerical approaches to represent complex socio-physical systems, and the most relevant interactions among them (e.g., energy, agriculture, the economic system). From a set of input assumptions, they produce outputs in the form of quantified scenarios: energy system transitions, land use transitions, economic effects of mitigation, emissions trajectories, to explore potential climate policy strategies. They are a heterogeneous category: IAMs can be built on rather different assumptions, represent the same processes with different levels of details or follow distinct logics.

IAMs and the scenarios they produce have grown central to the work of the IPCC "Working Group III" on mitigation of climate change, and they play an increasingly important part in climate negotiations and policies. It is not an old, well-established field of research, but still a relatively emergent one: its organisation and stabilisation is ongoing, which gives an insight into the emergence, structuration and establishment of a scientific collective/community that combines inputs from a diversity of disciplines.

How and where did the IAM community organise as such, and what is it made of? How can we characterise the "policy-relevance" of IAM research? What makes IAM policy-relevant and how important has this been for the recent organisation of IAM research? How is the connection with the climate regime (understood as the various institutions related to climate negotiations) organised, through which channels does it operate? In particular, we will consider the relationship of IAM research with the IPCC and with the EU.

One key aspect of our approach is that we will consider the devices (IAMs), the products (scenarios, papers, reports) and the people and institutions (researchers, research institutes, conferences, networks, research projects) taking part in IAM research as contributing to, and shaped by, this process of building a scientific community able to produce a specific kind of policy-relevant foreknowledge. The paper will describe how, and under which circumstances, researchers, models, and scenarios have been brought together to inform discussions about climate change mitigation.

To analyse the two features mentioned above, we will rely on literature and concepts from studies of climate (fore-)knowledge, epistemic communities, and the making of scientific collectives (drawing in particular on science and technology studies and laboratory studies). There already exists several bridges across those literatures: for instance, Meyer & Molyneux-Hodgson, 2010, 2016 and Demortain, 2017) have called for more detailed descriptions of the emergence and organisation of epistemic communities, relying on STS literature and approaches to enrich the concept; studies of the making of climate knowledge have investigated both its relationship to policy relevance and the devices and institutions for producing, sharing and exchanging data-laden, model-based or interdisciplinary knowledge (Edwards et al., 2011; Sundberg, 2010).

We also conducted a series of interviews with modellers and experts of this community, participated to scientific events, and analysed the main research programs and the material produced (reports, articles…). In our contribution, we will stress the role of research programs conducted in specific forums (e.g the Energy Modeling Forum coordinated by Stanford University, EU FP7 projects…) in the setting of the modelling research agenda and the production of scenarios, and analyse how they contribute to frame the content of IPCC WG III, in particular within the 5th Assessment report. We will also investigate how, by fostering common problem definitions and methodological approaches, they have contributed to institute these modeling approaches as a reference in climate expertise and policy.

This paper 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. 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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Bruno Dorin, CSH, UMIFRE MAE-CNRS, New Delhi and CIRAD-CIRED, and Pierre-Benoit Joly, INRA Research director, LISIS: **"A political economy of global agricultural modelling"

Since the late 1960s and the work of Jay Forrester (1971), global modelling has been used widely to construct images of future earth systems. These models do not try to refine the theory or produce knowledge through experiments (Morgan, 2012). They are aimed at constructing virtual realities and to throw light on possible future evolutions of the earth system. Their importance is indexed on concerns related to the planetary boundaries (Rockstrom et al., 2009), which go back to Malthus's magnum opus *An Essay on the Principle of Population as it Affects the Future Improvement of Society,* first published in 1798. However, global modelling has been important only since the 1960s and in relation, particularly, to food security during the 1960s and 1970s, liberalisation of international trade during the 1980s (Cornilleau, 2016) and, from the 1990s, in relation to climate change (Dahan, 2007; Edwards, 2010).

The making and use of global models raise several questions including: what are the policy implications of these models and the futures they produce? What do these models make (in)visible? What are the links between global modelling and public decision-making at different levels? Do these models close down (produce virtual realities that should not be discussed) or open up (provide tools to explore a plurality of possible futures) (Stirling, 2008)? And, how do these models perform as boundary objects that connect different social worlds (Star and Griesemer, 1989), that is, diverse scientific communities and policy-making practices?

In this paper, we focus on global agricultural (and food) modelling to address these questions. Agriculture and food have attracted renewed interest since the beginning of the 2000s for two main reasons. One is related to the importance of Land Use and Land Use Change and Forestry (LULUCF) in climate change models. The other is the international hike in food prices that occurred in 2007-08 and which led many agricultural and development economists to denounce the lack of interest in agriculture, since the mid-1980s, from both the academic and the donor communities (Janvry, 2010).

These dynamics have highlighted the role of economics (notably agricultural and development economics) as an evidence tool and a technology of power (Desrosières, 2008). To analyse the political economy of global agricultural modelling, we adopt two complementary perspectives. In the first section, we provide a brief socio-history of global agricultural modelling since the 1960s; in the second, we describe a specific modelling experience called Agribiom, which differs greatly from the mainstream models. The first perspective allows us to show structural trends in global agricultural models and the second reveals (through a kind of negative revelation, to use a photography metaphor) some political dimensions made invisible by the former models.

In both sections, our socio-historical analysis illustrates what Alain Desrosières (2008) points to, that economic modelling is context dependent and that knowledge and politics are coproduced (see also Jasanoff, 2004). In particular, we show that genealogies of ways of knowing are the product of interactions between epistemic communities and institutional strategies. We demonstrate also that path-dependency, related to technical devices that support modelling and epistemic communities, creates strong irreversibilities in modelling methods and tends, generally, to legitimate a narrow set of solutions to world agriculture and food production and, hence, future land use and access to resources. All these models are value laden and, as Pritchard et al. (2016) suggest, analysing their production, frameworks, calculations, tools and the ideas that shape these models "helps us to understand how, for instance, certain solutions to world hunger – such as large-scale land deals geared towards production of commodity crops for export – 'make sense,' while other solutions – such as large-scale land reform to feed the poor – seem radical and unlikely in the current conjuncture (Wolford, 2015)."

In this context, Agribiom – and its use in a collective foresight experiment called Agrimonde – constitutes an alternative way to design and use a quantitative tool. Agribiom and Agrimonde were conceived in the French tradition of foresight, in which modelling and scenarios are used to construct desired futures and to test their consistency and viability. As we will see, Agribiom's modelling strategy captures issues that are not visible in mainstream models, for instance, the importance of animal products in our diets. A number of agro-ecologists and agricultural political economists had previously highlighted this (see Weis, 2007 for a synthesis) and denounced "the biophysical contradictions of the industrial grain-oilseed-livestock complex" (Weis, 2013), or the "meatification of diets", that is, "the conversion of grain into flesh" which "diverts grain from the poor who cannot afford meat, and puts pressure on forests and marine ecosystems" (Friedmann, 2016). However, in the absence of quantitative global agriculture models able to show how a breakthrough scenario in food diets can change the global picture on land use, the issue was overlooked in mainstream agricultural economics. Agribiom could support such a breakthrough diet scenario, which put diet centre stage. It opened up a space for a dialogue on this issue (and other issues) thanks to a quantitative platform that can accommodate diverse knowledge and expertise. In this regard, Pritchard et al. stress that

> *Dichotomies such as science and lay knowledge, colonial and native, expert and commoner are not manifestations of good or bad approaches; they, and the knowledge they index, all express a set of social relations and material conditions that shape individual and collective understandings of the way the world works.* [In fact,] *Knowledge is clearly a product of political histories.* (Pritchard et al., 2016: 5;8)

which our socio-historical analysis of Agribiom helps also to illuminate.

On the basis of this analysis, we make three general statements on global agricultural modelling. The first is a plea for plurality in modelling methods. As this paper shows, each model type is based on different worldviews, different epistemologies and different ontologies. Each also corresponds to a different epistemic community and a different political agenda, and embodies different conceptions of the interactions between economics as a scientific discipline, and policy. Each way of modelling has its strengths and weaknesses. Some construct virtual realities, others construct real virtualities. The quantitative strength of models with a deep mathematical basis should not outweigh the fact that their results are not real, but are the result of a set of assumptions and constraints related to the phenomena represented. As shown by many scholars, the magic of numbers makes one tend to forget this (Porter, 1995). Hence, at a time when the standardisation of models is at stake, it is important not to forget the benefits of plurality in modelling methods. Plurality is crucial for improving the interactions between modelling, policy-making and the democratic process.

The second statement emphasises support for non-mainstream ways of modelling, such as are described in this paper using Agribiom. Based on our analysis, we concur with Hoffman (2016), who identified three basic characteristics of models intended to deal seriously with the Anthropocene:

(1) The objective of the model should be to explore alternative trajectories and communicate understanding. The emphasis should be on learning rather than prediction or prescription. To this end, the model needs to be transparent, accessible to a wide range of users, modular and flexible if it is to be continuously updated and maintained.

(2) The model must synthesise both the domain of economics with its focus on the behaviour of agents and exchange among agents, and the domain of the biophysical world with its focus on processes, both naturally occurring and purposeful, and the flows of materials and energy among them.

(3) The model must be global in scale to accommodate the concepts of biophysical limits and planetary boundaries, but must be spatially disaggregated to accommodate differences and exchanges among regions. A minimum of three regions would be required, but probably not more than ten.

This leads to our third statement, which is related to the way we model human-nature interactions. Trapped in a Newtonian conceptual system, economists have integrated nature as a set of functional resources. This ontological reductionism is accompanied by the artificialisation of nature and the idea that technology is a substitute for natural resources. The Green Revolution is at the core of the modernisation of agriculture, and its standardised technological packages are at the core of economic modelling. This ontological reductionism is playing a role in debate over land sparing and land sharing. The basic conceptions of nature are not commensurable. Agribiom attempts to show the way forward, in the direction of flexible models that pay attention to nature.

David Guéranger, Ponts Paris Tech and LATTS: « Instilling fear, yet not being hated. Explaining the political strength of an IT infrastructure for the maintenance of road networks »

The paper focuses on a vast IT system used in the area of the greater Nantes, an inter-municipal institution called "Nantes Métropole", since the 2000s. The IT system is called PIVERT, which stands for « Patrimoine Informatisé de Voirie pour l'Entretien, la Réparation et les Travaux neufs ». It combines a massive database, a set of IT tools to input data from the field and a visual interface (a mapping tool). This infrastructure altogether is meant to assist decision making, to plan maintenance work over 2800 kilometers of road with a high level of precision, at the metropolitan level. PIVERT helps centralizing and steering road works, planning them, defining their technical content and cost.

Despite technical appearances, road maintenance is a high-stake subject. Financially, the costs are high. Maintenance on roads implies work on surrounding properties attached to these roads. The programme is highly visible and concrete for the public, and decisively influences the way mayors and their policies are perceived. Road maintenance is an issue for which mayors remain accountable, due to their general competence on security matters that mayors share with the State (the "préfets"). Far from being a mere technical matter delegated to engineers, road maintenance emerges on the contrary as a highly sensitive issue for mayors. An IT system to manage the states of road and plan road maintenance effectively disempowers mayors to act on an issue which they would prefer to keep under their purview.

The case thus opens an interesting puzzle: why would mayors at all accept that their administration has recourse to an IT system that so directly impinges on their powers, and contributes to legitimate an intervention at the metropolitan level ? A first mode of explanation of this puzzle consists in stressing the effects of socialization among local political elites, and the rules of the local inter-city political games (Vignon). A second mode of explanation rests in the argument that the adoption of such an IT systems illustrates the expansion of technocracy and of the administrative apparatus, gaining ground, thanks to its expertise, on local elected elites (Thoenig). A complementary explanation is that local administrations are populated by younger staff, who seek to gain autonomy from political principals, mayors particularly (Desage).

Those explanations do not suffice to account for the fact that mayors were very quick to embrace the system, at a time of large political turnover (the 2008 council elections), at the heart of a mixed metropolitan administration, mainly controlled by cities and their mayors. Another way of explaining the existence of PIVERT is thus needed to account for the mayors' acceptance of this tool.

The development of this sociotechnical system is comprised of three phases. The first is an intensive audit of the local road system, investigating the state of the 2800 km of network in 33400 chunks, and the collection of 37 individual data points for each of these. The second phase is the development of the software program, by an external commercial company. The program fulfils functions ranging from inventory, research and investigation, statistical computation, all fitted within a centralized database. The third phase consists in the development of a broader system, called Nomade, to facilitate the daily input of data in the system from the field, and the visualization of the data. The entire system involves the work of several dozen people who administer the system, produce and edit statistical results, inspect roads and put data in the system.

The PIVERT system, overall, has three attributes which, I argue, make it a legitimate tool for mayors. The first is that it was initially framed as a solution to a problem, or threat. It emerged in a context filled with the rhetoric of risk, danger, threat. An early investigation of the state of the road network led to point to potential hitherto unknown failures of the network, and various critical situations. Those were immediately framed as threats for the quality of public environments, for the safety of road users, as well as a loss of road so-called “patrimonial” value. All of these threats resonated in a particularly intense and vivid manner for mayors around 2008, a time when public budgets and finances were largely perceived to be in crisis. In this context, optimizing investment and maintenance of the road network emerged as an imperative, and an IT system of the kind of PIVERT, as an appropriate solution — the right tool to avert this multi-dimensional, looming crisis.

The second attribute of PIVERT is its political flexibility. Technical criteria are not imposed on mayors, who enjoy a capacity to negotiate road projects with central metropolitan services. These negotiations are strictly framed by the outputs of PIVERT though. The system automatically defines priorities, which may be adjusted through the negotiations between mayors and the administrative staff, but that can not be ignored altogether. Those priorities are defined on the basis of a set of technical information, defined in categories and rubrics that are built in the system. The priorities are defined geographically, through maps that do not feature the boundaries of cities. Mayors may negotiate, but hardly control the information that frames these negotiations. They face a large flow of data, updated on a daily basis, with which they can hardly keep up. They can not simply exit from these technical discussions either, as this would imply accounting for a threat on the global budgetary balance of the system, and for infringing previous political commitments, which would represent a huge political cost.

The third aspect of PIVERT that plays out in the favor of its development and adoption is the organizational infrastructure of the system. A large number of administrative staff, in charge of road maintenance, patrol the network day after day to collect information about the state of the network, and input data in the system. Other staff, located in the central office of the metropolitan administration, centralize the information and design policies. In this two-level set-up, mayors keep control over their staff. A conscious political choice was made not to transfer this staff to the central metropolitan services. This being said, the existence of PIVERT substantially changes the activity of this local staff, whose time spent inspecting roads, collecting standard information, inputing it in the system, producing reports, and so on, has increased in important ways. The system also implies a whole new set of competences, and criteria to evaluate administrative work and to manage professional careers. In other words, the existence of an inter-city IT system substantially decreases the autonomy of the local staff.

Overall, PIVERT does more than anticipating issues and predicting critical states of the road network. Its main function is one of planning and programmation. It helps containing road investments within defined budgets; it helps defining hierarchies and priorities among the requests stemming from mayors, seen as the cause of the inflation of this budget. It strictly frames negotiations with and between mayors, providing a common informational basis for this negotiation, and legitimate criteria for collective decisions. The system, furthermore, is managerial: it organizes the division of labour, helps controlling field-level agents, provides a basis for evaluating their work and the results of road policy. In other words, while anticipation or prediction of future problems in the road network legitimized the introduction of the tool, its continued use is due to a host of other functions, and particularly to the fact that it supports the ongoing rationalization of inter-city administration on a financial, technical and managerial level. Anticipation, however crucial it is, is only effective in so far as it intertwines with an activity of rationalization, that is commonplace in the administrative sphere (Weber).

The specificity of the kind of anticipation that the system brings about is two-fold. First, with this system, the administration appropriates a dark prophecy: that of the progressive, invisible decay of the road network, understood as a common material capital ("patrimoine viaire"), that, for various reasons, may turn irreversible. The political strength of the projection and anticipation relies on the risk there is *not to act* or *not to do something* about the situation. In other words, with the system comes an imperative agenda. With the system, the administration in charge both puts forwards the threat, and immediately provides the means to address and avert it (maintaining a given level of financial investment…). In a nutshell, the strength of the system has mainly to do with its dialectal capacity to both instill fear and provide reassurance – a way of achieving the Machiavellian ideal of the Prince who knows how to be feared, without being hated.

The second noteworthy aspect of this case, as concern prediction, is the belief in the tool itself and its predictions. The predictive value of the tool has quickly become secondary to all other aspects. Its predictions never actually get challenged or trialed, as if the actual relevance of the predictions were of secondary importance. More important is the capacity of the tool to inform, to give meaning to the action of the administration and mayors, to their very engagement in this career and success. In other words, the legitimacy of a predictive or anticipatory tool such as this IT system, stems less from its capacity to accurately predict road infrastructural risks, than from the capacity of the tool and of its predictions to give meaning to administrative and political practices of those involved in this policy. As Festinger *et alii* have shown, a failed prophecy, however wrong, still helped Millennials regain a sense of belonging and solidarity. Similarly here, the substance of the prophecy matters less than the extent to which it supports the roles people are motivated to play, and reinforces their identity.

Céline Granjou, IRSTEA and University Grenoble Alps: "Politics of environmental anticipation: predicting global changes and securing nature in the ecotrons"

While environmental issues and human/nature entanglements have often been thought of in terms of geographical connexions, spatial proximities and global networks, little attention has been to how environmental changes reconfigure our relations to the future. Yet as climate change scenarios and forecasts circulate in an ever wider range of scientific communities and sectors, present agendas and practices increasingly re-align toward predictive and anticipatory objectives. My communication addresses how the anticipation of global changes is coming to the fore as an emerging field of expertise and practice in ecology; rather than depicting an all-encompassing Regime of anticipation, I aim to contribute to critically scrutinizing the various and situated assemblages of practices, imaginaries and material infrastructures enabling ecologists to anticipate the joint futures of nature and society.

I propose to think through the case of ecological research infrastructures called 'ecotrons', which are large instruments designed to produce experimentally valid knowledge through the controlled manipulation of closed, artificial ecosystems. Two ecotrons have been recently built in France at the end of the 2000s, under the Très Grandes Infrastructures de Recherche (TGIR) unit of the National Centre for Scientific Research (CNRS), which customarily operates the 'very large instruments' for subatomic and cosmological physics. Ecotrons allow for long-term, strictly controlled experiments in which researchers simulate future climates and observe and measure their effects on the ecosystem (i.e. soil, air, plants and small animals) enclosed and isolated from any outside contamination. I propose to consider ecotrons as sites for the re-alignment of ecological research narratives around prediction, anticipation and securization promises. As ecotrons enable the live simulation of the environmental conditions anticipated in global warming scenarios, they both encapsulate ecology's ambition to become an unsentimental 'hard' science and materialise the promissory vocation of ecology to secure the resilience of those 'ecosystem services' critical to human life on earth.

While science and technology studies has tended to address biomedicine, nanotechnologies and synthetic biology in its attention to expectations, promises and futures in the life sciences, closer attention should be paid to the ongoing reconfiguration of ecology's promise, which increasingly departs from biodiversity conservation and nature protection to stress the discipline's contribution to human development and survival in a warming world, by securing nature itself as a vital infrastructure to society. With the ecotrons, those promises are not only speech acts but are also clearly embedded and performed in material objects and infrastructures' configurations which heavily contribute to shaping, stabilizing and fostering our possible, probable and 'desirable' futures.

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Francis Lee, University of Uppsala: "Where is Zika? Four challenges of emerging knowledge infrastructures for pandemic surveillance"

Today, pandemics are increasingly known through novel and emerging digital knowledge infrastructures. For example, algorithms for disease classification, genetic and geographical information systems, as well as models of contagion, travel, or ecology. These digital knowledge infrastructures are constantly humming in different disease control organizations across the globe. In the west the US CDC, the WHO, and the European CDC are endlessly monitoring their screens, attempting to detect the next big outbreak of disease. These knowledge infrastructures are increasingly reshaping our global knowledge about disease and pandemics. Through these tools, new disease patterns become objects of intervention, new outbreaks become visible, and new ways of classifying the world come into being.

The general purpose of this paper, is to inquire into how emerging knowledge infrastructures—such as algorithms and modeling—shape knowledge production about pandemics. In doing this, the paper speaks to at least two overarching problems. First, how disease surveillance is reshaped by these emerging knowledge infrastructures. Second, how algorithms and modeling enter into processes of knowledge production more generally. In engaging with these questions through the lens of disease surveillance the paper outlines four challenges in dealing with algorithmic and modelled knowledge production:

1. The challenge of quantwashing judgment

How human judgment becomes machinic

2. The challenge of absent absences

How lack of data is represented (or not) in disease surveillance.

3. The challenge of subsuming of different styles of reasoning

How different ways of knowing the world become subsumed under a dominant mode of knowing.

4. The challenge of assigning agency between human experts and knowledge infrastructures

How actors struggle to decide if experts or systems should make decisions or not.

These four challenges point to some complexities and challenges with producing knowledge using algorithmic systems, that speak to how computation can take root in policy and governance.

To investigate these general problems this paper examines a particular case of disease surveillance: the algorithm that produces the "current zika state" of the world at the European Center for Disease Control and Prevention—the ECDC. The "current zika state" takes the form of a map of the world where countries are classified in eight categories outlining the intensity of zika virus transmission in each country or region. The algorithm and map are in constant flux. Both the algorithm and map are being updated, tinkered with, and revised. It might never stabilize completely—it is an infrastructure in constant making. Hence this paper is a snapshot of both the algorithm, and the map. They are still in flux.

In order to disentangle how the “current zika state” is produced, this paper draws on actor-network theory sensibilities which emphasize how agency emerges in complex assemblages of humans and non-humans. The point of this move is to highlight the complex relations between human expertise, computer algorithms, and disease classification. There is no straightforward answer to how the algorithm is intertwined with the ECDC. It is in complex and situated practices that the algorithm does the work. This means that the “current zika state” is constantly negotiated in practice.

How does disease surveillance know disease? Thinking with cases in space and time

The production of maps by counting disease-cases in space and time lies at the heart of epdemiology. Enumerating cases in time and space have been an essential part of the epidemiologists toolkit, ever since the iconic British epidemiologist John Snow tracked down the source of the 19th century cholera outbreak in London using a geographical map that plotted cholera cases. One might say that tracking cases in space and time is one the foundational cornerstones for epidemiological visualization and thinking. Hence, cases in space and time are constantly visualized in epidemiology—in epicurves (charts of cases over time), contact tracing charts, and maps. When, where, and how many cases can be said to be the epidemiological foundation for understanding disease.

However, these emerging knowledge infrastructures are challenging and changing these ingrained ways of producing knowledge about disease. Using these new knowledge infrastructures, disease surveillance organizations increasingly leverage new forms of tracking disease. These new infrastructures also challenge and reshape how disease outbreaks are known, visualized, and acted on.

Challenge 1. How human judgment is quantwashed in knowledge infrastructures.

The first challenge we will deal with here is how human judgment is folded with the production of invisible and shifting classification boundaries in producing the “current zika state.” This first challenge concerns, how the zika algorithm handles “reported confirmed cases” a seemingly simple and unambiguous measure of zika in time and space. However, this seemingly simple measure of zika intensity is made flexible and folded with expert judgment in the design of the zika algorithm.

What the algorithm’s designers are concerned with, is that not every country on the globe has a good disease surveillance system. And based on this, the question is, should each data-point—each zika case—be counted in the same way? The fact of the matter is that in producing the “current zika state” the boundary between different disease classifications is not equal for all countries. *Values are embedded in the algorithm.*

At the ECDC the zika classification algorithm is designed to ask: Does the country or region have diagnostic capacity? Timely reporting? An arboviral surveillance system? That is, what is the judged quality of the surveillance system in the country? If these qualities are deemed on the better end of the spectrum—by a human expert—the boundary between different disease states can shift. Hence, cases are not counted in the same way. However, although the boundary between zika-country and not-zika-country moves around in the zika algorithm, the classifications shown on the map are unambiguous.

Consequently, my first point is that *there is a mismatch between visual representation and algorithmic calculation*. The shifting boundary between different zika classifications of countries, are not represented in the map of the “current zika state”. There is no trace of ambiguity or shifting boundaries in the map. The categories and classifications look unambiguous and homogeneous, but in reality there are a number of judgment calls that are made in the database that are not visualized on the map. My second point is that *expert judgment is “quantwashed”* by being folded into an algorithm. What seems, at first, to be a promise of algorithmic objectivity and automation, instead folds many layers of human judgment and values.

Challenge 2. Absent absences

Our second challenge pertains to the representation of data absence. For example: The African country Chad is thought to be an epidemiological white spot on the map. There is simply very little or no surveillance data on zika from Chad. The question for the ECDC is how to include those areas of the world that do not have well-functioning disease surveillance? Regardless of the quality of the zika algorithm, the rigor of definitions, and the depth of expert judgment—certain places do not have disease data—and are thus invisible to the algorithm.

However, it’s not just that the data about zika in Chad might be absent, it’s also how absences of data are rendered visible in the “current zika state”. On the map, rather than representing the absence of data as a white spot on the map, the absence is represented in the same way as “zero reported cases”. Thus, white represents both the absence of data and the absence of zika. When I discussed this challenge with my informant at the ECDC he argued that it would be possible to add a dimension of uncertainty to the map, but also that data representation on the “current zika state” was constrained by what people expect of disease surveillance maps. Visualizations can only carry a limited amount of information to be useful.

Consequently, a further challenge for making disease surveillance algorithmic is that contexts of data production are difficult to visualize. Here the issue of representing and assessing absences comes to the fore—a zero does not necessarily mean the same thing as no data—but how are different forms of absences represented?

Challenge 3: The folding of different styles of reasoning

While disease surveillance is said to need clear-cut geopolitical maps, the worlds disease ecology is complex, messy and unruly. Many questions arise in algorithmically classifying the world in regional disease states: For example: How does a disease travel the world? In the case of zika, this question is closely tied to the range and habits of the *aedes aegypti* mosquito. How does this infamous beast travel? Where does it not travel? And how then do you map the ranges of mosquitos and viruses onto a political map?

There are multiple issues that the algorithm takes into account: First, is *aedes aegypti* “expected to be present”? Second, does the area “share a physical ground border” with an area where zika exists? Third, are they part of the “same ecological zone”? Fourth, is there “evidence of year round dengue virus transmission”—as the dengue disease is also carried by the same mosquito? Each of these questions entangle the boundaries of disease transmission with biologies, ecologies, and climates.

An example: is the island of Sri Lanka ecologically connected to India? On the scale of a world map, Sri Lanka and Tamil Nadu look quite separate, but on a more detailed scale there is a series of shoals and small islands that connect Sri Lanka and Tamil Nadu in India. This series of shoals and islands, which is called Rama's Bridge or Adam's bridge, might connect the two land masses for the *aedes aegypti* mosquito? Does Rama's bridge make them connected territories in terms of zika-transmisssion? This is the geographical way of knowing the world.

The zika algorithm also incorporates other ways of knowing the world. It incorporates climate data to model where the *aedes aegypti* might roam. It incorporates evidence of year round dengue virus transmission to infer mosquito presence—as the mosquito transmits both diseases.

The point I wish to make here is that the zika algorithm includes a number of different styles of knowing the world. What is said to be a map of zika cases in the world—the historically ingrained way of knowing disease in epidemiology—subsumes different ways of thinking about and knowing disease.

Challenge 4. Valuing agency between expert and algorithm

This brings us to the fourth challenge. How to handle the tension between geopolitical cartography, and messy ecology in practice? How to keep producing a new zika world map, week after week, month after month, year after year? The tension is that some believe that there needs to be "expert based judgment" on whether a country is contiguous with another or not.

This could potentially mean a huge amount manual work for an other people in the organization—who would rather see more automation. As we have seen above, there is huge amount of complexities in translating disease data to an unequivocal map of a pandemic. Thus, the production of the "current zika state" is potentially a very time consuming endeavor. The alluring promise of algorithmic smoothness threatens to fall apart in the face of the complexities of disease surveillance.

The ECDC thus faces an algorithmic dilemma. What knowledge production is possible to translate into automate algorithmic form? What is the cost of translating the world's *aedes aegypti* ecology into geopolitical space? How much resources does it take to manually judge neighboring countries each month? The maintenance and creation of infrastructures is not free—it takes constant work. Folding judgment into algorithms is not free. There are very different types of costs that need to be paid, and these costs can be moved around with algorithms.

So what do actors think is a good division of labor between humans and machines? What jobs do they want to delegate to our newfangled knowledge infrastructures? How do the actors value expert judgment, and in which situations is expert judgment deemed more valuable than the automation that a machine promises? Under which circumstances do actors want to delegate, for what reasons, and measured by which yardsticks?

In conclusion, I return to our four challenges and discuss three levels of politics, where the "current zika state" is concerned, and discuss how these different facets of the zika state algorithm become intertwined with sociotechnical politics, showing how the politics of nations, organizations, experts, classification, and representation are intertwined with the work of producing an algorithm. The normativities of the knowledge infrastructures of pandemic surveillance seem to push the idea of the simplicity and predictability of global disease flows, but the promise of algorithmic predictability stands in stark contrast with the complexities and tinkering that it takes to make algorithmic systems work. This raises questions about what dominant normativities become embedded in algorithmic systems. And what a good knowledge infrastructure needs to be?

Adrian Mackenzie, Lancaster University: "Techniques of the Predictor: generalizing complex populations"

'Predictors' in machine learning – the domain of prediction I will be discussing – refer to variables or features forming part of a model used in inference or prediction. They are the so-called 'independent variables' in the statistical models that underpin nearly all machine learning. There is wordplay in the title: 'the predictor' echoes 'the observer', the key figure/term in Jonathan Crary's book, Techniques of the Observer: On Vision and Modernity in the Nineteenth Century (Crary 1992).

Though obviously one who sees, an observer is more importantly one who sees within a prescribed set of possibilities, one who is embedded in a system of conventions and limitations (Crary 1992, 6).

Crary argues that seeing was transformed in the nineteenth century through the constitution of an observer, someone who sees in particular ways. The constitution of the observer required a set of scientific and cultural practices concerning vision. These practices remake 'the individual as observer into something calculable and regularizable and . . . human vision into something measurable and thus exchangeable' (17). In the process, seeing itself was autonomized in apparatuses and devices (stereoscopes, kaleidoscopes, zootropes, etc) associated with an increasingly disciplined work of vision(19).

Like Crary, I will suggest that prediction is presently undergoing a transformation, a transformation that changes both the position of the predictor as an individual person and the predictor as data. Prediction is inseparable from the practices, techniques, institutions and procedures of subjectification. In tandem, prediction, like sight, is being 'autonomized' in a plurality of ways. My general argument here is that the plurality of predictors – people and variables – have become much more like a population, the unruly multiplicities that were the conventional target of governmentality. That is, populations of predictors (people and data) become the general object of regulation as they multiply around predictions. A particular predictive operation – generalization – lies at the centre of this proliferation.

I'm working with one provisional illustrative example: the 'Passenger Screening Algorithm Challenge – Improve the Accuracy of the Department of Homeland Security threat recognition algorithms' (https: //www.kaggle.com/c/passenger-screening-algorithm-challenge/data), a 'data challenge' currently running on the data science/machine learning competition site/platform, Kaggle.com: Currently, TSA [U.S. Transportation Security Administration] purchases updated algorithms exclusively from the manufacturers of the scanning equipment used. These algorithms are proprietary, expensive, and often released in long cycles. In this competition, TSA is stepping outside their established procurement process and is challenging the broader data science community to help improve the accuracy of their threat prediction algorithms. Using a dataset of images collected on the latest generation of scanners, participants are challenged to identify the presence of simulated threats under a variety of object types, clothing types, and body types. Even a modest decrease in false alarms will help TSA significantly improve the passenger experience while maintaining high levels of security. Passenger Screening Algorithm Challenge, Kaggle The predictions that might be made about 'threats' would affect passengers lives quite directly, mostly in the form of the length of time, and associated anxieties, of queuing at airport security in the USA. Not exactly a policy problem, it definitely concerns governmentality and populations.

This illustration will lead me to the conclusion that Emerging regulatory dilemmas and controversies associated with prediction revolve around the interplay, mutability, proliferation and diversity of predictors, both in the sense of people doing predictive work and the ongoing transformation of all forms of data (images, sounds, measurements, transactions, speech, text, etc.) into predictors. It multiplies predictors in the sense of the group of people or crowds involved in predicting. It multiplies predictors in the sense of subsuming data in and across almost any sector as predictors. The learning in machine learning, I have suggested too, attests not simply to an automation or autonomisation of prediction, but to the gradual accumulation of regimes of observation, examining and testing suited to the comparison of many predictions. Machine learning, I have suggested, has a platform reality. The learning in machine learning, its capacity to deal with complexity, attests to the accumulation of regimes of observation and their partial delegation to non-humans. The capacity of machine learners to generalize, I have suggested, depends on both a loss of specificity for predictors (hence, machine learners come from many places, and can even be marshalled in crowds, as Kaggle.com does), and a generalization of regimes of prediction (so that the same kinds of models used in fisheries management will appear in passenger threat detection or astronomy).

What do 'techniques of the predictor' mean for governance of prediction? It might mean re-thinking the premise of restriction to specificity, or the idea that the regulation of machine learning should be sector-specific, to use the language of the Royal Society report. At simplest, what I have described suggests that differences between the general and the specific, differences that have been regarded as axiomatic in emerging policies governing machine learning, do not maintain a stable configuration. That is, it may not be possible to hold on to site or sector specificity in thinking about the governance of machine learning-based forms of prediction. The sectors are, it seems, re-defined by the plurality of predictors and the generalization of prediction. What does it mean that machine learners in France might be developing the predictive models that change the flow of passengers through security checkpoints at LA or Atlanta airports?

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Grégoire Mallard, Graduate Institute of International and Development Studies: "The Art of Simulation: Speech Norms and Social Glue in Middle East Disarmament Talks"

How do international security experts and policymakers come to talk about the future when their respective countries are at war? Do specific speech norms prevent diplomatic discussions from turning into acrimonious attacks or deceptive manipulations? This article argues that the use of simulations based on what I call "forward analogies" (when a foreign past-present relation is compared to one's present-future relation) allow nuclear disarmament experts to productively engage in diplomatic talks in a particularly hard context: the deliberations of the Weapons of Mass Destruction (WMD) Free Zone in the Middle East.

This presentation is based on a series of discontinuous observations in more than a dozen track-II talks on the WMD Free Zone, which took place from 2008 up to 2014. These observations have been conducted using a methodology that I call "alert participation" rather than "participant observation." Conducting "alert participation" requires to challenge certain objectivist epistemological assumptions often found in the literature on epistemic communities and transnational fields. In particular, alert participation helps us to analyze from within the temporal underpinnings of these talks—e.g. the "punctured" or discontinuous temporality in which these meetings take place, which alternates between thin and thick moments of encounters. Thus, the presentation not only discusses the cognitive models and speech norms exemplified by these qualitative simulations, but the social glue and strategic logics that animate the inner circle of meeting organizers. The presentation concludes that active participation of the sociologist/historian into the organization of such talks promises important analytical payoffs for social scientists.

In situations in which diplomacy is blocked by the unwillingness of parties to start negotiations, this presentation claims that the projection of another region's past (here, Europe in the 1950s) onto the future of the region (here, the Middle East of the 2020s) can serve a useful constitutive purpose in diplomatic talks. Indeed, such simulations help "constitute" the reality of regional orders when their ontological status as objects of deliberation and intervention is problematic. Furthermore, by encouraging role-shifting strategies, simulations also turn diplomats into students and commentators of a history that is foreign to them, which allows them to focus on forward-looking deliberations rather than on the contentious discussion of their own past and present grievances.

Evidently, the use of analogies such as those between Europe and the Middle East does not fall within the "prudential" style of reasoning, as analogies build relations between only two cases. Thus, their use in policymaking worlds cannot be associated with the increasing importance of the "large numbers" (Desrosières 1993). The use of analogies rather falls within the realm of what Ginzburg (1979) as well as Aradau and van Munster (2011:14, 31) call "conjectural" knowledge practices. These conjectural modes of reasoning consist in gathering a wide range of disparate evidence, which is analyzed for its incongruence and singularity, and which is always placed within a context that is assumed to be historically specific. An analogy respects the irreducibility of each context. Each of the two cases that form the analogy is analyzed as a whole, and in ways that are very similar to what political scientists have called the "holistic approach" to the practice of paired comparison (Ragin, 1989). In this conjectural style of reasoning, neither of the two cases can be reduced to the illustration of a general (and transhistorical) category, in contra-distinction with the prudential mode of reasoning already mentioned.

In fact, the analogy is a relation of similitude drawn between a set of relations within two cases, not between two cases (as a metaphor is). For instance, as is illustrated in the graphic above (figure 1), a "historical analogy" relates four different observable (hence past) moments in two different contexts. The analogy makes a claim about the *observed* similitude between the cases based on the similarity of the relations between the two moments within each case. Similarly, what I call a "forward analogy" underlines the *assumed* relation of similitude between two cases in different temporalities (in one case, the two moments are in the past; in the other case, one moment is past/present and the other is located in the future).

These forward analogies are not always used for predictive purposes. Participants in track-II meetings who used such forward analogies to structure discussions seemed to nurture the fictional quality of the great plans and roadmaps which they proposed for the Middle East in the context of their non-official discussions. The lack of realism of their plans did not seem to hurt the credibility of the participants, nor their desire to meet again, quite the contrary. Creative thinking and adventurous analogical reasoning seemed more valued in track-II meetings than a realist description of the problems plaguing the solutions to the problems of the Middle East. Still, not all track-II meetings deploy analogies, which means that the use of analogies in such social performances thus needs to be analyzed as a cultural phenomenon, whose autonomy is to be ascertained and explained.

In contrast, whereas narrative creativity might be valued over verisimilitude in track-II meetings, prudent realism might trump creativity in official negotiations. Here, it is assumed that a shift in context—from informal to official talks for instance—is likely to change the criteria by which the usefulness of such analogies are assessed. As soon as the analogy moves to official diplomatic forums, the veracity and plausibility of the assumed relation of similitude between two sets of relations (within the past of Europe and within the future history of the Middle East), will be officially questioned, tested, criticized or even rejected without any prior analysis. Within real-life negotiations, the fiction may not be able to resist the test of historical accuracy, and the analogy may lose its performative effects, especially if it clashes with common narratives about the Middle East's past, present and future. This is why diplomats may discuss the utility of forward analogies only to the extent that they know—and routinely gesture at the fact—that they are being discussed for the sake of the exercise, despite being unrealistic. In the case under study, the analogy worked differently from a metaphor, as those experts who used the analogy were careful to emphasize both the similarities between both contexts and some important differences.

So far, the literature that looks at the significance of knowledge practices designed to envision the future, such as modeling, forecasting, and scenario planning, has emphasized the predictive use of metaphors and comparisons: their use by policy makers to foresee the likely consequence of their action in a world of uncertainties, or their varying level of success (or failure) to predict likely outcomes (May, 1973; Jervis, 1976; Kuklick, 2006). But as this presentation claims, analogies used to talk about the future play an essential part in *constituting* strategic outcomes (such as a peaceful region) as objects of knowledge and intervention. Forward analogies can serve such constitutive purposes as they can give, in the present, a higher degree of reality to an unstable ontology (like a region) whose future existence and whose contours have yet to be defined. In the case under study, the commensuration made between "Europe" and the "Middle East" helped constitute the latter as an object of deliberation across former warring parties (Israel and Arab states).

By focusing on forward analogies, this presentation also expands the study of scenario-making exercises (Lakoff, 2007; Guilhot, 2011), which are routinely conducted to re-create geo-political threats in laboratory conditions. In contrast to other constructivist scholars of anticipatory knowledge practices, who have focused on future-oriented practices that help constitute catastrophic events and worst-case scenarios as objects of intervention (Aradau and Van Munster, 2011), this presentation examines how anticipatory knowledge constitutes best-case scenarios into objects of intervention.

Samuel Randalls, University College London, "Making resilience predictable: Exploring the predictive politics of the modelling and generation of resilience"

Is prediction still of value for resilience? This is the question this paper explores using the example of models for psychology and disaster risk reduction interventions. In Holling's (1973) classic terms, the question of whether the ecological system remains cohesive and persists in the face of perturbation means that precise prediction is not required as management is less about plans for equilibrium and maximum sustained yield, and is rather focused on open and reflexive systems that can absorb unexpected future events. Interventions to enhance a systems overall resilience therefore render prediction of events less vital. But in this paper I explore how through the resilience scales and indices that have emerged over the last few decades, resilience becomes not just a measure, but something that can be predicted and intervened in (enhanced). While resilience holds unpredictability and predictability together in tension (Aradau, 2014), attempts to predict resilience and interventions to improve resilience have become important in some fields. Resilience is no uniform, unilineal concept and therefore resilience is deployed in multiple ways each with different geographies, temporalities, and political implications (Simon and Randalls, 2016). To understand the politics of resilience and its predictions, we have to look at where it is put into practice and the kinds of ontologies and politics invoked or foreclosed.

In the case of psychology and mental health, resilience is frequently deemed as the ability of an individual to bounce back in the face of adversity. While rarely referencing Holling or ecological work, psychological sites of resilience have become increasingly visible in adverts, on websites, and through health care providers. But when it comes to specific welfare concerns, practitioners wish to be able to identify likely failures of resilience in advance. There have therefore been a multiplicity of attempts in psychology to try and predict, model and then intervene to enhance and build resilience. This includes using resilience indices to predict depression and using social-psychological factors to predict how individuals will respond to, for example, a natural disaster or spousal loss. What these do is try to create models to identify factors that shape resilience and then model and predict groups of people that are likely to be less resilient and intervene. Individuals at risk are identified and categorised, with interventions designed to target those specific risk modifying factors that the subject is deemed to be inadequate in. Rather than just project a scattergun of psychological resources at all people, by potentially identifying risk factors, interventions can become more specific. At one level, this is mobilised as an ethic of care, but on another it can also function as a way of defining which strategies and persons it is cost-effective to intervene with/in.

In the case of disaster risk response there is a growing focus on resilience, but in an environment where catastrophe risk modelling is increasingly developing complex ways to model integrated social-ecological systems and a government approach that increasingly monitors development assistance through the administration of cost-benefit analysis. The key challenge is that given the risk reduction goals that are set and the resilience matrices that are defined, proving that these interventions have the desired effect of enhancing system resilience is particularly tricky in the case of infrequent extreme events. This is where modelling and predicting both resilience but more importantly the enhancing of resilience through specific interventions, becomes an important way of justifying development intervention projects. As these models attempt to incorporate more social factors, they offer the potential to predict future system resilience and future societal responses to events in a much more comprehensive way than just testing, for example, engineering resilience in infrastructure. Resilience enables and requires the incorporation of the social and this potentially enables governmental intervention to continue to be justified in development and disaster risk reduction financing. Equally, however, these strategies might open the space for more individualised insurance-led approaches too or spaces where communities are deemed too lacking in resilient to be cost-effective for intervention.

I therefore argue that prediction via models and tests is precisely called on to ensure that the system persists in the eventuality of a future significant empirical test. It is not sufficient just to intervene at all cost or allow systems to self-unfold in too open-ended a way. The promise of resilience provides no promise of security (Aradau, 2014), or the prevention of events that will exceed the resilience of the system, but there is an interest in using predictive tools to predict responses to such events. Not least predicting responses could enable decision-makers to align these to the judgement of cost effectiveness of particular kinds of system interventions. This may inculcate new ethics of acting and caring in the world, or equally be productive of new biopolitics in which some lives are to flourish but not all. Indeed, such productivity might also become performative in bringing such lives and non-lives into being. Exploring the character of prediction and futures through these differing resilience sites therefore invites a political and philosophical questioning about the goals sought for and the kinds of politics at stake. As Simon and Randalls (2016) argue resilience general is too vague and open to be contested or accepted. Rather, by exploring different sites of resilience, we can ask more specific questions about how prediction and resilience are coupled together in particular practices and communities and evaluate their specific political and philosophical implications.

Dirk Scheer, Institute for Technology Assessment and Systems Analysis (ITAS), KIT, Karlsruhe: "A framework conceptualizing scientific simulation and policy-making"

Computer simulations are a crucial innovation in the field of information and communication technologies and have established themselves as an important tool with a wide variety of applications in science, business, and industry. It is primarily in basic and applied science that simulations play a significant role as an additional epistemic methodological approach alongside theory and experimentation. However, knowledge gained from computer simulations is not limited to the scientific community itself, but also affects other domains of society such as politics, business and industry, and the public at large. The production of simulation-based knowledge and its communication to political decision-makers have become crucial factors within policy-making. Thus, simulations fulfil two principal functions: they serve as instruments of both knowledge production and knowledge communication at the science-policy interface. The presentation conceptualizes epistemic simulation and policy-making at the science-policy interface, exploring boundaries between scientific knowledge production and political action. Initial thoughts on and preliminary ideas about this conceptualization have been explored in various publications (e.g. Scheer 2011, Scheer 2013, Kissinger et al. 2014; Scheer 2015, Scheer et al. 2015, Scheer 2017a, Scheer 2017b, Kissinger et al. 2017, Scheer et al. 2017).

A systemic perspective: Simulation modes of knowledge and communication

Scientific simulation at the science-policy interface fulfills a twofold task. On one hand, it serves as a knowledge instrument, generating scientific expertise and know-how. On the other hand, it serves as a communication instrument, transferring knowledge from the scientific to the policy community (cf. Table 1).

Scientific simulations serve as a knowledge-production instrument and complement the well-established scientific methods of theory and experimentation. Sociology and philosophy of science differentiate four different ideal types of scientific knowledge: secure and unsecure knowledge, and recognized and un-recognized non-knowledge. While the first three types are accessible to scientific analysis and specification, unrecognized non-knowledge remains in the field of theoretical constructs and is not accessible to further scientific – or other – specification, due to its unknown-unknown character.

First, secure and solid knowledge in the modern understanding of science is of a temporal nature and remains valid as long as it is not falsified by repeated validity tests. Simulations and their results contribute to solid knowledge when several types of uncertainties along the production process remain as low as possible, and reliability towards the target system is guaranteed. Ideally, initial and boundary conditions, as well as cause-impact relationships of the target system, are well known and can be transformed congruently into a virtual computer environment. Using methods of verification and validation, computer simulations can be tested for reliability.

Table 1: Types of knowledge and communication

Modes of knowledge		
secure knowledge	*unsecure knowledge*	*recognized non-knowledge*

full target system knowledge transferability of target system on computer successful verification and validation	nature of uncertainty range of uncertainty methodological unreliability value diversity	knowledge deficits early warning tool but limited to point on outside phenomena
Modes of communication		
enabling communication	*amplifying communication*	*feedback on communication*
specify and visualize foresight knowledge methodical and thematic interface for communicators	modelers act as political voices simulations as dialogue and communication platform	simulation results shape the way we think the world new visual components enter our cognitive patterns

Source: own elaboration

Second, uncertain knowledge covers the large area where evidence and knowledge are in fact produced, but the range of (quantifiable) uncertainty remains considerable. Thus, the validity of scientific results is restricted by particular ranges of uncertainty. Types of uncertainty within the modeling exercise are manifold and may refer to the nature of uncertainty (epistemic, ontic), the range of uncertainty (statistical, scenario), methodological unreliability, and value diversity (Petersen 2006).

Third, simulations may contribute to the area of recognized non-knowledge when they hint at existing knowledge deficits and risks and thus demonstrate and evidence known unknowns. While doing so, they serve as an important early warning tool for the policy system, indicating emerging problems and policy issues. However, the early warning potential of simulation is limited, since simulations have difficulties discovering new and completely unknown issues, which are not already implemented in the cause-effect relation of the model itself.

Scientific simulations at the science-policy interface may also be considered from a communication perspective. Considering simulations impacting communication, I distinguish three types of communication modes: scientific simulations may enable, amplify, and provide feedback on communication and/or communicators in the policy arena.

First, simulation modeling may enable communication, particularly through its projective and prognostic future orientation. It is able to specify and materialize future states of the world in the form of a virtual representation. By producing foresight knowledge, simulations may initiate and enable discourses among decision-makers and within the society as a whole on available options to shape, design, and decide the future. Future-oriented simulations are an important foresight tool to gauge possible future pathways which are, for instance, not accessible to empirics. Hence, 'editing' the future via simulation studies serves as an important communication object to stimulate reflections and deliberations on future developments.

Second, simulation as a communication object may reactivate the communication process itself – thus, simulations may amplify communication to the extent that the number of corresponding modelers and simulation scientists increases. By establishing, institutionalizing, and networking a scientific simulation community, the communication potential increases. Where simulations address topics relevant to policy, they serve as a dialogue and communication platform, stimulating actors to pick up the topics. In this way, simulations serve as a topic-selection and agenda setting mechanism.

Third, simulations may also provide feedback on how communication evolves and how communicators think and act. Scientific simulations, with their inherent number- and solution-oriented characteristics, may influence the cognitive thinking patterns and conceptual worlds of communicators – thus, they might impact how we think issues. Warnke (2002) argues that computer simulation, as a method of knowledge production, will bring in new visual components, which inevitably shapes how engineers think issues. However, the way simulations influence communication and communicators alike have so far not been systematically researched.

An impact perspective: Simulation use by policy

Scientific simulations at the science-policy interface raise the question of how the political system and corresponding decision-makers use provided research. Following policy advice and research impact literature (e.g. Weiss 1979; Renn 1995; Williams et al. 1997; Nutley et al. 2007), I propose four research use categories: First, the instrumental use embeds science in acts, rules, and laws. Simulations can be used in rule-making for technology support programs, regulation, and assessment, serving for evaluation and control measures. Second, the conceptual use of simulation research results in better knowledge among decision makers. Thus, simulations contribute to early problem perception (e.g. climate modeling), delivering evidence (e.g. life-cycle assessment), and illustrating the consequences of future policy options. Third, the strategic use of simulation data may be motivated by party competition seeking office during election campaigns, by justifying action of office holders during political windows of opportunities, or by a desire to stall for time. Fourth, the procedural use of simulation centers on encouraging networking for technology development, conflict avoidance and consensus making (e.g. technology procurement, collaborative research). However, what should be stressed is the fact that these categories are of analytical value, since they are sometimes difficult to apply empirically and the boundaries between different categories are often blurred (Nutley et al. 2007). In **Table 2**, I illustrate and demonstrate how computer simulations may specifically contribute to the four research use types.

Table 2: Types of research use by policy

Research use by policy	
Instrumental use	Identification and evaluation of policy options Design and implementation of policy decisions Impact assessment and monitoring
Conceptual use	Problem identification and understanding Coded knowledge archive Early warning tool
Strategic use	Legitimacy base for normative positions Scientific façade for interests and values Technical manipulation of simulations
Procedural use	Knowledge communication towards lay people and non-experts Conflict avoidance and consensus making

	Networking and actor integration

Source: adapted from Scheer 2013

An evaluation perspective: Quality assessment of simulations

A key question is how involved policy-makers evaluate and assess the reliability of scientific simulations. Based on interviews with decision-makers in a case study on geo-science modeling in the field of Carbon Capture and Storage (Scheer 2013, Scheer 2015), I deduced a set of assessment criteria for how decision-makers evaluate scientific simulations.

The interviews revealed a broad variety of quality variables, which can be roughly summarized in the following interview quotation: "The crucial questions always are: who did the simulation, who participated in it, what about the used methodology, and were all currently known facts considered in setting up the simulation." The evaluation criteria elicited from the interviews cover two different areas, namely simulation-inherent and simulation-contextual assessment criteria. While simulation-inherent variables are predominately used by decision-makers and experts with geo-scientific and simulation background, contextual criteria assessment are applied by experts lacking geo-scientific and simulation expertise. **Table 3** summarizes the set of evaluation criteria for assessing scientific simulations.

Table 3: Evaluation criteria for assessing simulations

Quality of simulation process and results	
Model-inherent evaluation	*Model contextual evaluation*
data boundary conditions assumptions parameter model causality balancing model vs. reality	source (author, institution) discourse among experts study comparison level of disciplinary knowledge integration and participation of experts

Source: adapted from Scheer 2015

Simulation-inherent aspects encompass a broad range of specific simulation components, namely data input, setting of boundary conditions and underlying assumptions, parameters and their corresponding values, the model and algorithms used, considered natural laws and causalities, and finally, balancing the model versus reality. Thus, simulation quality is evaluated from an inside perspective. According to the interviews, simulations are considered excellent when they include empirical data with a small range of error assessment, and rely on well-defined boundary conditions and underlying main assumptions. The parameters and impact variables should be tested for quality (e.g. sensitivity and uncertainty analysis) in order to ensure that only high-impact parameters for simulations are used. The model itself should be simple and not conflict with reality, while the software needs to be validated (e.g. by model benchmarking and comparison). Moreover, the underlying laws of the target system should be well understood and adequately transformed into computer language. Balancing simulations with reality and real-world phenomena is another important criterion.

When considering simulation-contextual criteria, decision-makers do not focus on simulation specifics in detail, but rely on what might be called ‘mediated’ criteria. The interviews revealed five contextual quality criteria in total, namely the source of the simulation, the reception discourse within the scientific community, the comparison of simulation results with similar studies, the level of knowledge in the corresponding discipline, and the degree of stakeholder participation in the simulation process.

The simulation-inherent and -contextual criteria deduced from the interviews revealed a broad range of quality aspects that are taken into account by decision-makers. However, if decision-makers are asked to evaluate a specific simulation study, they selectively focus on some criteria and disregard others. This became clear when researching the reception of a specific simulation study, the so-called Regional Pressure Study, which simulated underground pressure dispersion when injecting CO_2 (Schäfer et al., 2010). When asked how the regional pressure simulation data are evaluated for quality, interviews indicated that some quality criteria are obviously much more important than others are.

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