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Contested modelling: a critical examination of expert modelling in sustainability

ABSTRACT

We discuss the role of expert modelling in sustainability using a framework designed to improve the effectiveness of the modelling process. Based on the development of a set of reflective questions that can be used at certain key stages in the lifecycle of projects developing such models, we discuss how using the framework would lead to improvements in the coupling of the process of expert modelling with the process of intervention, which is implied by the existence of the expert modelling project. This questioning pushes the development of a framework beyond considerations of ontology and epistemology into issues of axiology and praxis, extending the notion of contested modelling beyond the narrow scientific sense to a wider social setting. Our framework has been developed through a case study analysis of the effectiveness of four research initiatives that have used expert modelling to address the complexity of intervention in a sustainability context.

Keywords: Expert Modelling; Scientific Modelling; Problem Structuring Methods (PSMs); Sustainability; Effectiveness

1. INTRODUCTION

Computational models are widespread and increasingly becoming indispensable in decision-making about complex systems at a wide range of temporal and spatial scales. With the wider recognition of the complexity of contemporary sustainability challenges, society increasingly – and mostly unknowingly – relies on models for analysis and future projections. This paper originates from a discussion between two researchers who work in the separate fields of Planetary Boundaries and SoftOR/Problem Structuring Methods and reflects an attempt to better understand their respective philosophical positions. This has led us to investigate the role and function of expert modelling in real-world decision-making using an analytical framework based on assumptions made by modellers about ontology, epistemology, praxis,

and axiology. Our motivation is based on questioning the *effectiveness* of the projects that develop such models. We have used ‘project’ as a convenient label for the entity which contains and directs the modelling effort and provides the interface to the model(s)’ public(s). The interface may be tightly coupled, as in a commercial engagement between a supplier and a customer mediated by models; or completely uncoupled as in, for example, the case where the output from modelling is purely intended as contribution to scientific knowledge. This has also led us to consider the project as the unit of analysis rather than just the method of modelling carried out within the project.

We first of all review some of the current limitations in the development and use of expert models and then propose a method (framework) for the analysis of projects that develop and use such models. In the light of the issues raised, this paper reviews the modelling processes from four research projects ranging from local to global scale, in which modelling is being performed with a broad goal of informing experts and/or society generally about sustainability options.

2. REVIEW AND METHODOLOGY

Enormous investments are being made in the development of models of social-environmental and social-technological systems of escalating size and complication via the agency of government and industry funded research (e.g., (Cornell, Prentice, House, & Downy, 2012)). These models by nature are simplifications, structural representations of an *organic*, dynamic and complex reality.

The representation of complex systems in models in the sustainability context tends to follow a philosophy based on a pragmatic, realist conceptualization (Beven, 2002). Furthermore, the pragmatic limitations which arise from the difficult problem of parameterizing models and their detail complexity leads to an instrumentalist approach. The philosophical basis of such modelling is rarely interrogated, as explanatory power to describe phenomena is emphasized over explanatory depth (Beven, 2002). Whilst at the same time the content and structure of the models are increasingly opaque, even to other expert modellers (Anderson, 2010).

Winsberg argues that the “*roles of values in creating the models cannot be discerned after the fact—the models are too complex and the result of too much distributed epistemic labor*” (Winsberg, 2012, p. 111). Overpowering other representations and narratives, instrumental rationality is becoming pervasive (Kelly, 2003; Sanderson, 2006). As the purpose of models moves from being about “*advancing knowledge*” to “*informing action*”, reflection on the modelling process becomes immanently important (Boyd & Richerson, 2005; Helgeson, van der Linden, & Chabay, 2012). However, the purpose of modelling is rarely reflected on or stated by expert modelling practitioners in sustainability (Beven, 2002). Assessments of the confidence that can be held in the predictive power of models can verge on the arcane and are often methodologically incoherent as discussed in (Keenan, Carbone, Reichstein, & Richardson, 2011; Stainforth, Allen, Tredger, & Smith, 2007), but still have a powerful draw for the users of the output (e.g. (IPCC, 2007)).

Whilst Beven points us towards an explanation of expert modelling in terms of a pervasive, implicit, pragmatic realist stance he glosses over the origins of this position, except to say that such a stance “*seems quite natural*” and that the “*philosophical subtleties are not really necessary to the practicing environmental modeller, who only needs to know that achieving realism is still difficult in the practical prediction of complex environmental systems.*” This describes an apparent pedagogical gap; why are these philosophical underpinnings considered to be subtleties, and are they really unnecessary in practice? Bankes et al provide us with a sophisticated vision of what these underpinnings could be for the expert modeller, especially in terms of the validity and robustness of knowledge claims (Bankes, Lempert, & Popper, 2002). However their work is based on an analysis of Agent Based Modelling (ABM) specifically addressing the computational social science community and the expert modelling community in sustainability at large may have overlooked this. Encouragingly, four papers on modelling in sustainability *do* cite their work (Agusdinata & Dittmar, 2009; Barton, Ullah, & Bergin, 2010; Barton, Ullah, Bergin, Mitsova, & Sarjoughian, 2012; Zellner, Theis, Karunanithi, Garmestani, & Cabezas, 2008) suggesting there is some diffusion of knowledge into the sustainability community.

Beven's analysis firmly places philosophical underpinnings as subtleties that are not germane to the needs of the practicing expert modelling community in sustainability, despite the limited inroads made by Banks et al in the papers cited above. In contrast, the SoftOR/PSM community is far more used to reflecting on the philosophical assumptions behind modelling and understanding the paradigmatic boundaries arising from working in different research and practice traditions. For example, the range of differentiation that exists from modelling for objectivist prediction to the subjectivist position of elicitation of mental models, exploration of "what if" questions, and reflection (Pidd, 2004, p. 8). Unlike expert scientific modelling, which has one prevailing paradigm characterized by Beven as pragmatic (or naïve) realist, the SoftOR/PSM community encounters and uses a multiplicity of modelling approaches, which has led to the development of a number of organizing frameworks to assist in making their use effective. We cite three here as relevant to our work.

Firstly, the hard/soft systems paradigms, which are based on the basic dichotomies in philosophy between a positivist and phenomenological stance, and sociologically between functionalism and interpretivism, and provide a useful discrimination between a view of systems that can be engineered (hard) and the conceptual view of a system as an aid to a systemic process of inquiry into a problem situation (soft) (Checkland & Holwell, 2004). This work draws attention to an asymmetric complementarity between an ontological and an epistemological view of systems, claiming that by avoiding ontological commitment the epistemological position allows for many ways of viewing and interpreting the world. The characteristic pragmatic (naïve) realist position of the expert modeller in sustainability (Beven, 2002) would align with Checkland and Holwell's description of ontological commitment, albeit implicitly, and the classification of functionalism (Checkland & Holwell, 2004, p. 56). Signs of interpretivism might be seen to be encouraging. For example, the "*paradigmatic turn*" from realist to interpretivist described by Atkins et al in their use of the DPSIR¹ framework in managing the marine environment (Atkins, Gregory, Burdon, &

¹ Drivers Pressures State Changes Impacts Responses

Elliott, 2011). Whilst not strictly expert modelling in the sense we have been using, it does highlight a fruitful exchange of ideas from the PSM/SoftOR community into sustainability.

The System of Systems Methodologies (SoSM) (Jackson, 1993, 2000, 2003; Jackson & Keys, 1984) uses the four Burrell and Morgan paradigms of functionalism, interpretivism, radical structuralism, and radical humanism (Burrell & Morgan, 1979) as the theoretical underpinning to its development. The SoSM provides a means of characterizing and selecting intervention methods based on the classification of the complexity of systems and the diversity of participants' worldviews in the SoSM matrix. This matrix characterizes the problem situation along the systems dimension as either Simple or Complex, and on the diversity of participants' worldviews as Unitary, Plural or Coercive. The SoSM can thus be used to guide methodological choice. The original motivation for its development was to understand "*relative efficacy in solving problems in various real-world problem contexts*" (Jackson & Keys, 1984). Its particular relevance here is the alignment of the Unitary column with a functionalist underpinning. In the sustainability community, where philosophical underpinnings are rarely questioned, we see that the prevailing assumptions, whilst not stated explicitly, must be shared in and implicitly understood i.e. the Unitary column in the SoSM.

Whereas the implications of the epistemic shift described by Checkland and Holwell may be difficult to grasp, the implications of the Plural column of the SoSM are much easier to understand, and a plural context easier spot when it exists. Recognizing, looking for, or even acknowledging pluralism may be the first step a project takes towards acknowledging the notion of contested modelling.

Mingers has described an organizing framework for MS methods, first by characterizing the modelling assumptions of method(ologies) (sic) by their philosophical underpinnings in ontology, epistemology and axiology (Mingers, 2003), and then by a classification scheme for their deployment in a problem situation along one axis defined by the three Habermasian worlds – the Material, the Personal, and the Social – and along the other dimension the four phases of PSM intervention – Appreciate, Analyse, Assess, and Act (Mingers, 2003; Mingers & Brocklesby, 1997).

Mingers' framework offers the most compelling starting point for our own analysis since it explicitly deals with the fundamental philosophical assumptions behind modelling as well as the praxis – how to act. In addition, Mingers and Brockelsby specifically discuss the philosophical, cultural, and cognitive feasibility of working across seemingly incompatible paradigms (the incommensurability problem) to achieve multimethodology (Mingers & Brockelsby, 1997). It is the cultural and feasibility issues that interest us here. The *implicit* pragmatic realism of expert modelling described by (Beven, 2002) aligns well with the notion described by Mingers and Brockelsby of a *prevalent single culture*. Working in a plural context with methods originating in an interpretivist stance may well be incompatible with the worldview of expert modellers working in sustainability.

As discussed, we have the Hard/Soft, SoSM and Mingers' frameworks available to us and these guide our efforts. However, there is relevant work in the sustainability field, which we have incorporated into our analytical approach to address the weakness of frameworks that have originated mainly within an organizational, and not a wider social setting.

2.1 Ontology

Our first dimension of analysis revolves around the problem of ontology. Whilst the four Burrell and Morgan defined paradigms are well known to the SoftOR/PSM community we also make use of Geels' work in analysing socio-technical transitions towards sustainability as more relevant to the domain of the practical interventions for our four case studies (Geels, 2010). He argues that the following set of *seven* social-science ontologies (rational choice, evolutionary theory, structuralism, interpretivism, functionalism, conflict and power struggle, and relationism) is necessary to fully encompass the social theoretic underpinnings of the complexity of the transition to sustainability debate. Geels articulates what each of these paradigms assume about notions of agency and causal mechanisms and these become our key classification along the dimension for assessing a project's ontological position.

2.2 Epistemology

Our second dimension of analysis concerns epistemology. The results of scientific modelling, when enacted through simulation to emit predictive data, could be considered as knowledge creating. Frequently positioned within scenario exploration or what-if questioning to frame the use of these models, they enable scientists and engineers to explore areas of knowledge unobtainable through empirical approaches, either because it would be too expensive, remote, dangerous, or otherwise inaccessible, or because they are explicitly exploring possible future states.

We are right to question the validity of knowledge so created but there are strong arguments in favour of the affordances it offers (Bankes et al., 2002; Bryson, Ando, & Lehmann, 2007; Gilbert & Arhweiler, 2009; Winsberg, 2003). Bryson et al put forward a compelling case for treating the results from agent-based simulation as valid scientific method (Bryson et al., 2007). By constructing a strong argument on the validity of the methodology, they have made a convincing case that the results from numerical simulation are as scientifically worthy as empirical observations.

On the same theme, Winsberg appeals via metaphor to the notion that knowledge generated through experiment in conventional ‘laboratory’ science, and knowledge gained through numerical simulation should be viewed as equivalent in status (Winsberg, 2003). His argument is subtle in that whilst many numerical simulations start out as testing existing theory, they can throw up surprising results. It is this property of serendipity that is so appealing and examples have been summarized in the work of (Epstein, 2006; Gilbert & Troitzsch, 2005). However, there are drawbacks, Lorenz warns about the possibilities of making abductive fallacies arising from simulation (Lorenz, 2009).

Bankes et al specifically address the question of the effectiveness of computer epistemology “*how can we learn things about the world by performing computations*”? They usefully distinguish exploratory from predictive modelling and it is the former that is, epistemologically, more challenging to consider as valid, but potentially more rewarding in terms of insights offered. Gilbert and Ahrweiler argue for the effectiveness of simulation as a method in the social sciences and this mirrors our concern in this paper for concentrating on

the effectiveness of the overall project in which the modelling sits (Gilbert & Arhweiler, 2009). They introduce the long historical perspective into their argument based on the foundations of the social sciences and present a typology of simulation defined along an axis between *nomothetic* and *ideographic* explanation. In this paper we use this axis for our critical analysis of epistemic claims.

2.3 Praxis

Since the modelling activities can and do lead to real-world interventions, our third dimension is focused on praxis, by which we mean the way in which the theoretical knowledge of the expert modeller is enacted through intervention. By definition, we refer to the people conducting the modelling in these projects as expert modellers. The results from their modelling are then coupled to intervention by the engagement mechanism used by the project in which the modelling sits, and it is this engagement mechanism that is subject to analysis. This links to epistemology and the Aristotelian notion of theoretical, poietical, and practical knowledge. Understanding praxis is to address the question of understanding the knowledge necessary in order to achieve action.

Pickering's notion of the "*mangle of practice*" is useful here (Pickering, 1993, 1995), encouraged by Ormerod's recent exhortation of its value (Ormerod, 2013). We can therefore analyse praxis by looking at engagement as a "*dynamic process of intertwined elements*" (*ibid*). We also see a reflexive component to the question of praxis, drawing on (Doubleday, 2007; Macnaghten, Kearnes, & Wynne, 2005; Romm, 1998) who have translated the ideas of reflexivity from general social theory into the context of environmental governance. For our framework, reflexivity involves sensitivity to inputs from diverse perspectives, consciously recognizing that there are alternative ways of seeing issues of concern. It involves a deliberate consideration of whether all the necessary voices are present, and are being listened to.

2.4 Axiology

Our fourth and final dimension of analysis is axiology. Mingers uses the axiology dimension in his classification scheme to discern “*what is valued or considered right*” that underpins the *purpose* for modelling (Mingers, 2003, p. 559). Purpose is thus not an objective fact of modelling, it is instead imbued with values arising at the level of the individual expert modeller up to a societal level, and on the way encompassing the values which determined the existence of the modelling project in the first place. Relevant to the domain of the projects we are analysing, Winsberg offers insight into axiology in his work on the ethical debate about the problem of Uncertainty Quantification in climate modelling. He states:

“...the standard ways of using probabilities to separate ethical and social values from scientific practice cannot be applied in a great deal of climate modeling, because the roles of values in creating the models cannot be discerned after the fact—the models are too complex and the result of too much distributed epistemic labor.” (Winsberg, 2012)

Winsberg summarizes a number of arguments, but central to his analysis are two key places where value judgments are apparent in determining outcomes from modelling; the first concerns the judgments that are made when ascribing probabilities to hypotheses that are not outright refuted, and the second to the degree of belief to invest in a hypothesis given methodological choice (*ibid*). In our framework we suggest reflexive questions of this kind in an attempt to surface where value judgments have entered into a modelling project.

2.5 Summarizing questions

These four perspectives or dimensions of analysis have led us to propose the following questions which we believe need to be clearly addressed by any project in which expert modelling is central to its purpose. The list is not meant to be normative but indicative. We recognize that there is little point in using our framework as a classification tool, as in the case of Mingers’ work, when the purpose is to guide projects towards greater effectiveness. It is also not a question of supporting method selection, as in the case of the SoSM. However,

the epistemic shift described by Checkland and Holwell is closer in flavour to what we are trying to achieve. Our contribution lies in linking evaluative questioning at appropriate key stages in the project lifecycle with achieving project effectiveness.

Review Points:

1. At initial project design
2. At funding review, where these questions could be used to gate whether the project continues
3. At final evaluation, where these questions would contribute to the wider improvement of methodology within a specific modelling community (methodological learning) (Yearworth & White, 2014, p. 939).

These three review points have quite different characteristics. Initial project design is clearly the most important in terms of setting up a modelling project with the best opportunity to be effective. The second point at funding review really just gates the project; if it is clear that the project is unlikely to be effective then there is little point for it to be funded. The final evaluation provides an opportunity for subsequent and/or similar projects to be more effective.

Questions:

Ontology (O): What is the underpinning ontology for the project's methodology? Is there diversity in underpinning ontology? Is ontology made explicit, or self evident from the mode of writing used to communicate results?

Epistemology (E): What knowledge claims are made arising from the modelling? Where would we place these claims on the nomothetic/ideographic axis? What is the operating or prevalent research tradition that would judge the validity of knowledge claims arising from the modelling?

Praxis and the purpose of modelling (P): What is the (stated) purpose of modelling in the project? How best should the model purpose be expressed? Is it to constrain uncertainty, or at least better characterize the boundaries of uncertainty? Is modelling designed to guide action, or merely to predict, where action is beyond project scope? If modelling is directed towards action, how does it relate to an explicit process of action research? How does modelling support stakeholder engagement? What is the process of engagement with stakeholders? Does engagement persist beyond the project lifetime?

Axiology (A): How was the project funded? What methodological choices have been made by the project? What group of stakeholders does the project intend to serve? In what way have the results from modelling been interpreted by expert judgment to tailor the engagement process?

We also suggest the possibility of inconsistencies in stance by examining the six possible relationships between a project's position on Ontology, Epistemology, Axiology, and Praxis (i.e. $O \Leftrightarrow E$, $O \Leftrightarrow A$, $O \Leftrightarrow P$, $E \Leftrightarrow A$, $E \Leftrightarrow P$, $A \Leftrightarrow P$). We pose no specific questions but consider that a raised awareness of inconsistencies is a way of gaining further insight into possible lack of effectiveness.

3. PROJECT ANALYSIS

We have reviewed the modelling approaches taken in four projects. These projects aim to develop and use models to inform decision-making in either a social or business context. We have chosen these four projects in particular on the basis that the authors have been involved as research co-investigators or research student supervisors in these projects. Whilst we have attempted to base their analysis on facts, which appear in the published literature from the projects, we recognize that our analysis is clearly subjective. The framework we describe in §2 with a view to understanding what would have made the projects more effective has guided our analysis. Project details are summarized in Table 1 together with the conclusions from our analysis using the questions listed above. Sections 3.1 to 3.4 present our detailed analysis of the four projects.

3.1 Sympact – Exploring the environmental impact of digital transformation

The Sympact project (Tools for assessing the systemic impact of technology deployments on energy use and climate emissions) was funded by a grant under the UK Engineering and Physical Science Research Council (EPSRC) Transforming Energy Demand through Digital Innovation (TEDDI) program in partnership between the University of Bristol, Guardian News and Media (GNM) and the University of Surrey Centre for Environmental Strategy. The purpose of its modelling activity was to evaluate different future scenarios of how the news industry might look as a result of digital technology innovations, with a view to informing sustainability strategies. The approach adopted integrated environmental life-cycle assessment (LCA) techniques (Schien, Shabajee, Yearworth, & Preist, 2013) into systems modelling approaches (Yearworth, Schien, Preist, & Shabajee, 2011). This allowed quantitative energy and emissions analyses to be combined with more speculative models of technological and behavioural change, such as models of the uptake of electronic reader devices, e.g. tablets.

The underpinning ontology for the models developed in Sympact was clearly functionalist. The project has developed a system dynamics model that shows dynamic behaviour of a system comprising a producer and consumers of digital news media presented as a set of scenarios over a period of 10 years (Yearworth et al., 2011). The project also had to deal with modelling ‘at the next level down’; hence its use of detailed LCA in order to answer questions about an appropriate functional unit for analysis. For example, the geographic location of consumption emerged as a significant factor in determining energy footprint and emissions (Schien et al., 2013).

The purpose of Sympact’s system dynamics model was to support attempts to understand what factors are likely to influence the evolution of this system and to make predictions about greenhouse gas emission trends in the digital news media industry. The purpose of the detailed LCA model was to provide a clear understanding at a very detailed level about the environmental cost of consuming online news media (Schien et al., 2013).

The outputs from the project as published in (Schien, Preist, Yearworth, & Shabajee, 2012; Schien et al., 2013) make strong knowledge claims about the emissions arising from consuming online news media and would be considered towards the nomothetic end of our analytical spectrum.

The involvement of a major news industry player in the project is indicative of an emphasis on praxis, in terms of enabling advice on business strategy by addressing such questions as the impact of future carbon pricing. However, despite the co-development of the research with the prime user of its outputs, questions of axiology have not been addressed in the project's publications, and the role of stakeholders and their engagement is not clear in its documentation.

Overall we can see a project whose ontological position in functionalism reflects the cultural and cognitive preferences of the researchers involved, epistemic claims that are strongly nomothetic, and despite the good intentions of working closely with stakeholders in changing business practice, the project veered towards generating knowledge claims about energy use rather than achieving specific, documented changes in the industry in which it was positioned. This perhaps reflects its rather conventional funding source. Its eventual effectiveness will therefore more likely be judged on the quality of the knowledge claims it makes and as measured by indicators such as citation counts.

3.2 HalSTAR – the Halcrow Sustainability Toolkit and Rating System

HalSTAR was developed by the consultancy company Halcrow, now part of CH2M HILL, with the stated purpose of achieving a grounded, holistic approach to assessing sustainability (Pearce et al., 2011). It was designed as a flexible appraisal framework that ensures that a wide range of sustainability issues and options are considered in client consultations and with broader stakeholder groups as part of project planning, design and management.

HalSTAR's framework is based on Forum for the Future's five capitals model (natural←human and social←financial and manufactured). Its underpinning knowledge base

is populated with concepts drawn from a qualitative data analysis of an extensive body of relevant literature, ranging from formal guidelines and regulations through to current scientific publications on sustainability concerns, issues and requirements. Within the ‘five capitals’, HalSTAR further groups these concepts by stakeholder viewpoint ranging from client to project, end-user, local, regional and global. This framework was designed to allow for flexibility in use according to client needs, from detailed issues within schemes or projects to overall performance summaries. The current development of HalSTAR involves linking the diverse concepts within the framework, through the development of causal loop diagrams with the purpose of identifying potentially important feedback loops which could have an impact on the dynamic behaviour of solutions proposed through the use of the framework (Montgomery, 2012).

Although the initial elicitation of concepts from the literature was conducted through a process of qualitative analysis, their clustering into needs or capitals and grouping into stakeholder viewpoints produces a structural arrangement. This, coupled with the use of causal loop diagrams, suggests that the prevailing ontology for the project is functionalist.

Knowledge claims arising from the modelling in HalSTAR are difficult to judge since they arise purely in relation to the questions emerging from customers to CH2M HILL during the process of engagement. We can surmise that they would reside at the ideographic end of the spectrum we are using for analysis, the results from modelling being specific to the case in question and unlikely to be generalisable.

The praxis is clearly about stakeholder engagement in the exploration of sustainability options. HalSTAR has in effect *digested* a vast range of literature and presented it in a framework that makes it easier for stakeholders to engage with the material. Whilst the framework is still owned by the expert modellers in CH2M HILL, the engagement process is clearly intended to enact a change in behaviours with the clients. This method of engagement mediated through expert-owned models suggests a useful way forward that potentially offers a high degree of reflexivity.

The framework is being used to surface issues at different levels of concern to stakeholders but is not a methodology as such for reconciling conflicting stakeholder views. The on-going development of the causal loop diagrams could be used as a basis for group model-building activities, and thus approaches a more interpretivist stance (Montgomery, 2012). The latter may also go some way towards improving reflexivity, with both stakeholders and expert modellers learning more about sustainability issues through engagement over shared models of causal relationships derived from the original HalSTAR framework.

Questions of values are bound up in the methodological choices made by project and especially in the selection of source materials used to build the HalSTAR framework. These are less of an issue from a wider objective scientific point of view since the purpose of the framework is to inform project choice for CH2M HILL customers and questions of trust are implicit in the commercial relationship between the CH2M HILL and its customers.

In summary, the HalSTAR framework appears to be a highly effective modelling activity, which has strong emphasis on praxis and makes knowledge claims that are highly relevant to the specific problem situations arising between customers and CH2M HILL. Developments in group model building approaches suggest modelling is becoming more akin to that which Supports Problem Structuring methods (Yearworth & White, 2014).

3.3 CONVERGE – Rethinking globalization in the light of Contraction and Convergence

CONVERGE is a recently completed European Commission FP7 research project, involving academic and non-governmental organization partners from five countries. Its focus was on global sustainability, seeking to conceptualize equity for human societies within Earth's natural biophysical limits. It has also aimed to promote social learning and action, drawing lessons from existing sustainability activities at the community level in the partner nations.

In the project, system dynamics models were developed through consultation with community groups, integrating various measures of sustainability across scales and in different contexts. The stated purpose of these models is to investigate and promote adaptive management approaches (CONVERGE Project Team, 2009). Other project documents refer

to the value of models for supporting communication within the stakeholder communities and improving understanding of the complex system e.g. (Koca, Sverdrup, & CONVERGE Project Team, 2010). Yet at the same time, the project's approach involved taking models developed through these engagement events and applying them in other contexts e.g. (Kristinsdóttir, Ragnarsdóttir, Davíðsdóttir, Sverdrup, & CONVERGE Project Team, 2011).

Thus several underpinning ontologies have been apparent in CONVERGE's methodology and praxis. Ideas on interpretivism and power/conflict resolution were invoked in providing the rationale for the modelling consultation approach but have faded into the background as the project has developed. The ways in which the expert modellers actually developed the models were strongly functionalist; and structuralism was evident from the assumption that models developed about a particular issue or in a given community can be scaled up to the global or applied universally. The models were explicitly intended to guide action towards sustainable practices, and action research approaches was mentioned in the project work plan. The plurality of ontologies and model purposes had been recognized, and indeed the project included a specific work-package to reflect upon and address interdisciplinary challenges such as these.

We, the authors, were research advisors to CONVERGE (co-author Cornell was previously an investigator within the project). In this capacity, we have focused on issues of reflexivity in the project team's modes of working. There were two strands of research in the project involving engagement with community stakeholders – the more interpretivist analysis of cases of local sustainability initiatives, and the process of system dynamics model building. In the former, the engagement generally has involved a long-term relationship between researchers and communities (initiatives pre-dated the project and will continue beyond its life). In the latter, stakeholder engagement was episodic much more ad hoc. From this we can assume that the knowledge claims arising from the project would be classified as ideographic. The project team have noted some conceptual and practical tensions between these two distinct strands, which have made it difficult to draw robust lessons about the

extent to which the modelling supports more reflexive processes in stakeholder engagement and thus facilitated shifts towards more sustainable practices, as the project initially hoped.

3.4 IHOPE – *Integrated History and future of People on Earth*

IHOPE is a profoundly interdisciplinary research project linking social and environmental sciences to understand human-environment interactions over multiple timescales. It began at a Dahlem expert discussion workshop in 2005 (Costanza, Graumlich, & Steffen, 2006), evolving into an international collaborative project supported by a network of institutions and global change research programs within the Earth System Science Partnership². IHOPE's stated goals, as outlined in the research plan (Hibbard et al., 2010) are to:

- Map the global integrated record of human and biophysical change;
- Test social-environmental system models to understand the dynamics of those systems;
- and
- Project options for the future of humanity.

At present, the research plan text suggests that the end-goal for all the project effort is to “*improve quantitative models*”, an often unquestioned project aim in biophysical global change science. However, the modelling effort in this interdisciplinary project has been piecemeal – to date, the main focus of the initiative has been to gather a comparable database of regional examples of human-environment interactions. The project leadership has recently taken a more deliberate focus on modelling (Heckbert, 2013; Lemmen, 2014), primarily because it offers a way to identify and systematize “*suitable examples*” for expansion of the global evidence base on human-environment interaction. There is a more strongly recognized need to engage with a wider group of knowledge communities in the social sciences and

² The Earth System Science Partnership was the precursor to Future Earth, an international strategic collaborative program for global change research.

humanities, which is motivating fresh reflection on the purpose and use of modelling in this project.

Much of the formal documentation of this project strongly implies a functionalist ontology, but there has been some dissent and discussion about the nature and role of models and the modelling process in the project (Cornell, 2010; Cornell, Costanza, Sorlin, & van der Leeuw, 2010). Dearing et al. and Sörlin have reflected in depth upon the rationale for looking at the past in this way, and provide a nuanced analysis that addresses the functionalist/structuralist limitations and deterministic implications (Dearing, Braimoh, Reenberg, Turner, & van der Leeuw, 2010; Sorlin, 2011). At the very least, IHOPE's forward research plan needs to be developed further to say what these quantitative models might be for, and explain what kinds of processes the models will be deployed in. Above all, the research plan should recognize that new knowledge inputs they may actually transform, not merely slot into, the current functionalist content and procedures of Earth System modelling.

3.5 What-if Analysis at Review Points

The results summarized in Table 1 present our analysis of the four case study projects against the framework and questions we describe in section 2. This analysis was conducted on the basis of the project situation 'as-is'. However, having identified three critical review points at which project effectiveness could have been addressed we continue our analysis on the basis of asking 'what-if' questions. The three review points identified were i) initial project design, ii) funding review, and iii) final evaluation. We have noted already that these three points are quite different in their possible effect. Therefore, we reflect on what would have been the implications had our framework been used at each of these three points. For the funding review we concentrate on the implications for the funder, rather than the project. For evaluation we focus on the implications for projects of the broad characteristics of the example we have analysed. The results from this analysis are shown in Table 2. In this table the wording in each column should be read as if originating from different stakeholder views as follows i) Initial Design is from the point of view of the scientists/engineers proposing the project; ii) Funding Review from the point of view of funders or managers within an

organisation with the power to gate a project's continuation; and iii) Evaluation from either specialist evaluators, reviewers, or similar scientists/engineers proposing new or follow-up projects and wanting to learn from previous results.

4. DISCUSSION

While they address different scales, contexts and objectives, the modelling paradigm adopted by all four projects analysed is mostly functionalist and deterministic – that is, equations are being solved, and loops being closed (Geels, 2010). Such modelling activity easily becomes essentially instrumentalist or black-box in nature with the process and results owned by experts. This also reflects the apparent philosophical, cultural, and cognitive comfort zone of the expert modeller (Mingers & Brocklesby, 1997). We should not be surprised by this lock-in, it reflects nothing more than the pervasive pragmatic realist stance of the expert modeller (Beven, 2002).

The functionalist/structural account of complexity in dealing with sustainability issues and associated need for modelling and simulation approaches to explore dynamic behaviour (Fararo & Butts, 1999) mean that the expert modeller plays an essential role in bringing these models into existence and in their on-going ownership and control. It is this ownership and control that puts the models outside processes that would make them *debatable*. However, we believe that the expert modelling community needs to assume *a priori* that its models will be *contested*, both in the narrow scientific sense of falsifiable, but also as part of the wider social context in which the models' purpose is being enacted. The latter perhaps represents a Popperian ideal; expert models, ranging in scale from the specialized models developed by the projects discussed in this paper through to full-complexity Earth system models, are not just about making sense of laboratory science, they are becoming a necessary component of intervention in the social world.

The organizational cybernetics community recognizes the notion of second-order systems (self-aware, self adaptive) and understands the relationship to the social world, notably through the work of Luhmann (1995). Their modelling is structural but not deterministic.

Other examples exist: economic modelling around information asymmetries to understand emergent behaviours such as perverse incentives and moral hazard also give us structural but non-deterministic models (as discussed in (Ait-Sahalia & Hansen, 2010)) and also in (Macho-Stadler & Perez-Castrillo, 2001). Habermas's idea of communicative action is perhaps little known by the expert modelling community, but its emphasis on ensuring that citizens involved in public decision-making have the requisite capacities for engaging in informed debate resonates with sustainability concerns and has implications for modelling processes intended to inform sustainability decisions (Habermas, 1986).

However, by what mechanisms can this wider stakeholder engagement and debate come about? Methods based on argumentation (De Liddo, 2010), participatory action learning (Perkons & Brown, 2010), Issue Based Information Systems (IBIS) (Buckingham Shum, 2006; Conklin, 2003), and social learning (Senge, 2005) all offer possible solutions, either singly or in combination.

Ultimately we believe that it is the questions about modelling purpose (axiology) and praxis that are most important to address. In the context of sustainability, the intended outcome of much modelling is to bring about behaviour change – but is this a function of the model's epistemic claims (e.g. predictive accuracy) or the method of coupling the modelling process to social change? It could be argued that the latter is more important than the former, although some minimal level of accuracy is clearly required to judge the validity of any normative epistemic claims that are made. However, the balance of these options can never be tested if interventions based on predictions lead to changes that render the predictions obsolete. Answering these questions requires healthy and reflexive attitudes in the expert modelling community towards building models that are fit for purpose, rather than “right” (Box & Draper, 1987; Sterman, 2002). For example, what is the purpose of climate modelling? It is the largest social experiment based on modelling ever attempted – predictive mathematical models injected into the sightline of powerful decision-makers. Yet the climate modellers' prevailing functionalist worldview can make them unfortunate bedfellows with policy makers. Who has the view of the *real world*? Many of these experts hold onto the idea

of being “*not policy prescriptive*” (e.g., (IPCC, 2007)), but given knowledge derived from numerical predictions emitted by their models, intervention then becomes a moral question that cannot be avoided. The *system* that is the *object* of expert modellers’ attention is not “*out there*” and disconnected from the experts: they too are the system and their actions are not independent of it.

This raises axiological questions of reflexivity and scrutiny. Who owns the knowledge derived from stakeholder-engaged, use-oriented modelling, and how is it to be applied? Unfortunately most expert modelling approaches often seem stubbornly opaque. This can be due to the difficulty of creating suitable engagement processes, although HalSTAR suggests a way forward in an industry setting. To all intents and purposes, without appropriate stakeholder engagement, models become black-boxes that emit predictions, making knowledge claims on the way, but are not open to internal structural, or white-box, validation (Barlas, 1996). Attention then focuses on seeking agreement between models, rather than agreement on process that meets purpose. The paradigmatic expert modeller, constructing models to satisfy a narrow set of scientific criteria, denies a wider role for the modeller in the social processes that must mirror the very changes these models seek to explain. Where there is debate about models, this is likely to be around epistemic claims (e.g. black-box predictive accuracy) rather than informed white-box debate as part of normal praxis, *sensu* Barlas, in which model validation involves evaluation along a “*continuum of usefulness*”. It is notoriously difficult for the non-scientific public to understand the distinctions between ignorance, uncertainty and contingent findings, expressed as testable hypotheses (Spiegelhalter, Pearson, & Short, 2011) or aleatory and epistemic sources of uncertainty (Helton & Burmaster, 1996). These factors stultify engagement. By over-attention to being scientific we paradoxically close avenues for scientifically informed but *effective* interventions.

5. CONCLUSIONS

Modelling has become a specialized scientific endeavour largely disconnected from social processes, while holding the potential to shape society through its outputs. The four projects

we have analysed as case studies using our framing questions have the explicit aim of informing interventions in society. We have commented on the effectiveness of these projects in that aim, but more with the purpose of demonstrating how our framework could be used to steer towards greater effectiveness. We have further illustrated this by conducting a ‘what-if’ analysis at three critical stages in a project’s lifecycle and presented the possible implications on the project, the funders of such projects, and the wider eco-system of similar projects. Whilst it is our belief that we cannot ignore these *metaphysical* considerations when we talk about effectiveness of projects in the sustainability domain, we can see that Checkland and Holwell’s hard/soft characterization, Mingers’ framework and Jackson and Keys SoSM (Checkland & Holwell, 2004; Jackson & Keys, 1984; Mingers, 2003) are similar in that all of them at their core are attempting to address the effectiveness of intervention. Our key recommendation is that our questions need to be examined at certain key stages in a project’s lifecycle in order to improve the *overall* effectiveness of modelling projects, but that the effect of applying the questioning on any *specific* modelling project depends on the review point.

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Project	Description	Ontology	Epistemology	Axiology	Praxis
SYMPACT	Tools for assessing the systemic impact of technology deployments on energy use and climate emissions, in conjunction with the UK newspaper <i>The Guardian</i> . The research aims to develop methods and tools that would enable collaborative model building to take place at scale to enable shared learning over large sets of stakeholders, and to trial this with a user community associated with the technological transformation of the news publishing industry towards online media (Schien et al., 2013; Yearworth et al., 2011). Funding Body: UK EPSRC (EP/I000151/1)	Clearly functionalist	Strongly nomothetic	Defined by the publicly funded research program – transforming energy demand through digital innovation	Initial strong focus on industrial partnership
HalSTAR	A pre-sales engagement tool for structuring conversations between Halcrow (Now CH2MHILL), an environmental consultancy business, and its clients, in order to elicit requirements and design appropriate solutions within a multi-criteria sustainability framework (Pearce & Murry, 2010; Pearce, Murry, & Broyd, 2012). Funding Body:	Functionalism, with interpretivism entering through group model building	Difficult to judge, towards ideographic	Strong commercial interests in the company owned models	Clearly focused on stakeholder engagement and changing customer behaviours

	Private Venture (PV)				
CONVERGE	An action-oriented project with a multi-scale focus, involving community engagement on global sustainability issues. “CONVERGE recognizes the deep-rooted interconnections of environmental and socio-economic systems. A variety of systems thinking methods will be used to ‘re-conceptualize’ the ingredients and processes that produce the phenomena of globalization, in order to move towards a more sustainable and equitable path for the world’s inhabitants ³ .” (Fortnam, Cornell, Parker, & CONVERGE Project Team, 2010). Funding Body: (FP7-ENV-2008-1, project 227030)	Ideas on interpretivism and power/conflict resolution were invoked to provide project rationale. Actual model development strongly functionalist	Ideographic	Strong thematic program publicly funded	Strong community stakeholder engagement
IHOPE	A global research network, sponsored by International Human Dimensions Programme for Global Environmental Change and the International Geosphere-Biosphere Programme and linked projects. Global-scale, multi-timeframe analysis of dynamics of human-environment	Strongly functionalist, but with some discussion about limitations	Not clear, probably nomothetic	Clear vision for offering viable pathways for human development	The need to engage with a wider group of knowledge communities in

³ Extract from the 2009 CONVERGE Description of Works (DoW).

	interactions, drawing on contemporary Earth observation and socio-economic analysis, and historic, palaeoenvironmental and archaeological studies (Costanza et al., 2012). Funding Body: Consortium support ⁴				the social sciences and humanities has been recognized
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Table 1: Summary descriptions of four projects applying systems modelling approaches to sustainability challenges

Project	Initial Design	Funding Review	Evaluation
Sympact	Clarity on functionalist, nomothetic modelling which was to be publicly funded would have <i>relegated</i> concerns about praxis. The industry partner's role would have been reduced to sponsor (as it eventually became), rather than engaged by the project in an attempt to influence strategy directly	Whilst industry engagement and impact are crucial to the strategy of the funding body, the scientific community they fund must be <i>seen</i> to be doing excellent world-class science. Reviewing must ensure that the modelling methodology used is appropriate for delivering results that are publishable in high	Are the results from modelling <i>valid and reliable</i> such that they can be used as inputs to further modelling projects?

⁴ The main contributors to date are: the University of Uppsala (where the international project office is now hosted), Stockholm Resilience Center, US National Center for Ecological Analysis and Synthesis, the UK Natural Environment Research Council's QUEST program, Arizona State University, the Institute for Sustainable Solutions at Portland State University, the Australian National University's Climate Change Institute, the Doherty Foundation, the US National Center for Atmospheric Research and the Pacific Northwest National Laboratory.

		impact journals	
HalSTAR	Given that commercially owned models were designed to facilitate engagement with customers for possible sustainability projects, the project needed to find the appropriate balance between the functionalist origins of the tool, which could be generally applied or even published in the scientific literature, with the interpretivist/ideographic approach implicit in the group model building with customers.	Commercial organizations need to balance investment between R&D in modelling which is either functionalist/nomothetic, which would be of wider benefit to the sustainability community, or interpretivist/ideographic and focused on achieving successful commercial outcomes with specific customers. The former lends credibility to the organization but at the cost of investing in effort more usually funded by the normal funders of such research i.e. government bodies via their research agencies/councils, charitable foundations etc.	What has been the <i>return on investment</i> in the modelling activity? Is this a profitable business activity?
CONVERGE	Given the strong adherence to achieving the social transformation characterised as contraction and convergence (Meyer, 2000), is there a mismatch between the predominately functionalist modelling approach adopted and the axiology and praxis of the project?	The public funding bodies of research projects that are seeking to enact transformation rather than pure knowledge creation need to ensure that modelling approaches will lead to effective outcomes <i>and</i> deliver <i>methodological learning</i> for the wider community.	Was the approach to modelling <i>generalizable</i> ? Could the same approach be used by other projects to deliver effective modelling at the community level? Published results from the work package on interdisciplinary working will be valuable in answering these questions.

IHOPE	<p>The following quote from (Costanza et al., 2012) suggests a considerable challenge of integrating empirical, qualitative data with numerical modelling. “<i>The challenges of modeling future socio-ecological states numerically suggest that qualitative understanding of system behavior should be further developed. The objective here is to identify and develop general principles of socio-ecological system behavior, supported by empirical evidence drawn from long records of regional environmental change</i>”. It seems an open question whether there is appropriate methodology available within the group to deliver on this goal.</p>	<p>Group or consortium oversight of research into modelling could provide guidelines on appropriate modelling methodology especially if the group is comprised of leading figures and the guidelines were perceived as normative</p>	<p>How have the models developed by consortium members contributed to <i>achieving the vision</i>? Is there sufficient methodological influence within the consortium to guide other projects?</p>
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Table 2: Summary ‘what-if’ analysis using the framework at the three critical review points